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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

RECORD OF DEEP WELL DRILLING FOR 1904

BY

M. L. FULLER, E. F. LINES, and A. C. VEATCH

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
HYDROGRAPHIC BRANCH.
Washington, D. C., February 13, 1905.

SIR: I have the honor to transmit herewith a manuscript entitled "Record of Deep Well Drilling for 1904," prepared by Messrs. M. L. Fuller and E. F. Lines, but including certain material compiled from notes furnished by Mr. A. C. Veatch. The report presents the results of the first six months' work, with a system for the collection of well records and samples, formulated by Mr. Veatch and put in operation under the direction of Mr. Fuller, chief of the eastern section of the division of hydrology, on July 10, 1904. Mr. Veatch was assisted by Mr. Lines until September 15, when the work was relinquished to the latter. The report embodies the records of a large number of wells, for many of which sets of samples are preserved on file, and in addition gives an account of the development of the system and of the methods employed.

The principal aim of the report, as stated in the introduction, is to furnish drillers and present or prospective well owners a basis for future work and to afford geologists and others a more complete knowledge of the rock succession and structure. It is hoped that the report will lead to greater appreciation of the value of records by the driller and will serve to encourage the preservation of samples.

Very respectfully,

F. H. NEWELL, *Chief Engineer.*

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

RECORD OF DEEP WELL DRILLING FOR 1904.

By M. L. FULLER, E. F. LINES, and A. C. VEATCH.

INTRODUCTION.

In this report, which is the first of a proposed series of annual publications, are presented the results of the first six months' work by the United States Geological Survey in the systematic collection of well records and samples. Much time having been occupied in organization and preliminary correspondence, the results of only about three months' actual work are included. The report is issued for the purpose of giving to present or prospective well owners and drillers the results of drilling as reported to the Survey, with the object of furnishing them as good a basis as possible for future drilling in the regions discussed, and to afford geologists and others a more complete knowledge of the rock succession and structure.

It is intended that the reports of the series shall present records of contemporaneous drilling rather than the results of past work, a special attempt being made to secure records accompanied by samples. The logs of completed wells, however, will be incorporated when practicable; but as records of such wells are seldom preserved for any length of time, their number will probably decrease in proportion to new wells as the work continues.

All well records received during the year 1904 that were accompanied by complete sets of samples are presented in this report, as are also a considerable number furnished by drillers, contractors, well owners, etc., representing other completed wells. The report does not, however, include all records furnished the Survey, a great number being furnished by oil companies and others interested in the development of oil or mineral lands. Many of these are confidential and can not be published, while others will be compiled and embodied in reports on special regions, which will be published later.

Grateful acknowledgment is made to the following contractors and drillers who, by furnishing records or samples, have assisted the Survey in its endeavor to bring about a better knowledge of the strata penetrated in drilling. The asterisk (*) indicates that records of wells are given in whole or in part in the present report; in the other cases the records are either confidential or are reserved for special reports to be published later.

Principal contractors and drillers furnishing records.

Aggers, William A., Muscogee, Ind. T.
Akin, Mr., Wade avenue, Washington, Pa.
*Akins, E. J., driller for Reece, Heasley & Meals, Hundred, W. Va.
Archer, Kruger, Mississippi.
*Artesian Well and Supply Company, Dyer and Friendship streets, Providence, R. I.
*Barber, Lucien C., Scott, Cortland County, N. Y.
Barnes, R. B., Artesia, N. Mex.
Beach, O. C., Roswell, N. Mex.
*Bean, J. S., R. F. D. 65, Emlenton, Pa.
Birdsong, Mason, Bolton, Miss.
Bishop, Mr., Salt Lake City, Utah.
Black, Frank L., Waynesburg, Pa.
*Black, R. H., 423 John street, Braddock, Pa.
*Bliss, George R., Rye, N. Y.
*Bolles, William M., Franksville, Wis.
Borchers, W. F., 68 East Maiden street, Washington, Pa.
Brigham, W. J., Tunica, Miss.
Broiles, E., Artesia, N. Mex.
*Carman, George W., driller for G. W. Patterson, Stewartstown, Pa.
Carnegie Natural Gas Company, Carnegie Building, Pittsburg, Pa.
Carter Oil Company, Titusville, Pa.
*Champlin, F. A., East Longmeadow, Mass.
Chapman & Sperry, Artesia, N. Mex.
Chartiers Oil Company, Tradesmen's Building, Pittsburg, Pa.
Chesney & McCready, Muscogee, Ind. T.
*Christofferson, E., driller for J. F. McCarthy, Fertile, Minn.
*Cladek, Frank T., West Scott avenue, Rahway, N. J.
*Clifton, R. T., Velasco, Tex.
*Colwell, J. A., West Superior, Wis.
Cook, William J., Muscogee, Ind. T.
Cooper & Warren, Roswell, N. Mex.
*Copley, W. H., 828 Leonard street, Fostoria, Ohio.
*Craig, L. J., Rock Springs, Wyo.
Crane, G. S., Checotah, Ind. T.
*Crist, S. T., and Son, Codorus, York County, Pa.
Cunningham, J. B., Cliftonville, Miss.
*Danis, C. H., Coldspring Harbor, N. Y.
Devonian Oil Company, Pittsburg, Pa.
*Dibble & Ernest, Fullertown, Ohio.
*Dillon, J. B., Bowen, Pike County, Ark.
*Duck, Elmer J., driller for John McCool, New Freeport, Greene County, Pa.
*Dunlap, T. L., driller for J. B. Fishel, New Martinsville, W. Va.
Dunn, J. L., Dunns Station, Washington County, Pa.
Durst, F. A., Bellefourche, S. Dak.
*Eagen, Thomas, Poynette, Wis.
*Egan, James, driller for F. A. Champlin, Mansion House, Springfield, Mass.
Eisman, David, Washington Trust Building, Washington, Pa.
*Elliott, J., Mellville, N. Y.
Endly, W. J., Nowata, Ind. T.
English, A. Z., Muscogee, Ind. T.
*Espy, E., driller for J. F. McCarthy, Atwater, Minn.
*Faust, J. J., South Kaukauna, Wis.

Feigler, C. E., Minter City, Miss.
*Ford, John L., driller for J. A. Sutter, Pass Christian, Miss.
Forest Oil Company, 323 Fourth avenue, Pittsburg, Pa.
Forman, Grant, Muscogee, Ind. T.
*Fowler, Thomas, Corpus Christi, Tex.
Fox, J. A., Roswell, N. Mex.
Franklin Oil Company, Tyro, Kans.
Garner & Swerringen, Artesia, N. Mex.
*Gibson, Alex. T., West Winfield, Herkimer County, N. Y.
Gillespie, R. G., Pittsburg, Pa.
Goldsburg, Albert, Memphis, Tenn.
*Gorder, H. G., Dodgeville, Wis.
*Granberry, P. M., & Co., box 115, Houston, Tex.
*Grant, C. L., 17 Byron street, Providence, R. I.
Grayson, Harry, Washington Trust Building, Washington, Pa.
*Green, Charles L., 1160 Stuart street, Green Bay, Wis.
Greensboro Natural Gas Company, 808 Tradesmen's Building, Pittsburg, Pa.
Guffey & Queen, Pittsburg, Pa.
*Guffy & Galey, Pittsburg, Pa.
*Gunter Brothers, Stuttgart, Ark.
Hale, J. C., Artesia, N. Mex.
*Halterman, George G., Parowan, Utah.
*Hambrecht, H. W., superintendent for L. Wilson Well Company, 225 Dearborn street, Chicago, Ill.
*Hamilton, W. F., Ocala, Fla.
*Hammond, E. D., 120 Sargeant street, Hartford, Conn.
*Harmon, William, 226 East Market street, Tiffin, Ohio.
*Harper, Thomas B., Jenkintown, Pa.
*Harris, N. F., driller for Artesian Well and Supply Company, Providence, R. I.
*Hawk, John I., Selma, Ala.
Heath, E. N., Artesia, N. Mex.
*Heflin, J. O. & Co., 2004 Third avenue, Birmingham, Ala.
Henderson, J. B., McMillan, N. Mex.
*Hills, I. W., Medina, Wis.
*Howard, F., Canandaigua, Lenawee County, Mich.
Hulse, Jesse, Murray, Utah.
*Jameson, William, driller for St. Mary's Drilling Company, Lima, Ohio.
*Jenkins, E. A., Scottsville, N. Y.
Jennings Brothers, Pittsburg, Pa.
*Johnston, R. J., box 528, Burlington, Iowa.
*Jorgensen, H., driller for W. N. Bolles, Franksville, Wis.
Judd, W. E., Farmington, Utah.
Karns, S. E., Beaver, Pa.
Kelly Bros. & Cooper, Beaver, Pa.
Kennedy, W. C. & Co., Pittsburg, Pa.
*Kinney, James, jr., Bellaire, Ohio.
Klinkscale, Mr., Roswell, N. Mex.
*Knaack, Henry M., Station A, R. R. No. 5, Milwaukee, Wis.
*Knauf, M. F., driller for Artesian Well and Supply Company, Providence, R. I.
*Lambie, Robert, Drilling Company, Orrville, Ohio.
Larssen, Peter, Salt Lake City, Utah.
Lawrence Gas Company, Youngstown, Ohio.
*Lee, John H., 1702 Houston avenue, Houston, Tex.
Leonard, John, 63 West Chestnut street, Washington, Pa.

*Liberty Well Company, 7633 Bennett street, Pittsburg, Pa.
Lykins, W. C., Miami, Ind. T.
*Lyle, James, 349 North Main street, Washington, Pa.
*Lynch, Albert, Stamford, Conn.
McCausland, John, 33 West Walnut street, Washington, Pa.
*McDonald, J. J., driller for Smith & Thayer Company, Berlin, N. H.
*McDonald, R. H., driller for C. E. Gesin, Tidioute, Pa.
*McGuckin, J. B., driller for Thomas B. Harper, 5921 Beechwood street, Philadelphia, Pa.
McVay Brothers, Rockyford, Colo.
*Matteson & Zeigler, Bonsteel, S. Dak.
*Maule, Lewis, Copemish, Manistee County, Mich.
*Meloy, E. D., driller for Charles S. Wise, 2544 North Grand avenue, St. Louis, Mo.
*Mentzer, Frank, driller for Artesian Well and Supply Company, Providence, R. I.
*Miller's, W. J., Sons, Genoa Junction, Wis.
Monongahela Natural Gas Company, Oliver Building, Pittsburg, Pa.
Muno, P., McMillan, N. Mex.
Murdock, Baldwin & Co., Union Trust Building, Washington, Pa.
Natural Gas Company of West Virginia, 39 Vandergrift Building, Pittsburg, Pa.
*Nichols, L., driller for J. P. Miller Artesian Well Company, 39 Michigan street, Chicago, Ill.
Nicholson, W. I., Wagoner, Ind. T.
Norbeck & Nicholson, Redfield, S. Dak.
*O'Neill, James, 217 West College street, Albert Lea, Minn.
Oregon Short Line Engineering Department.
*Osborne, W. R., Metuchen, N. J.
*Pannewitz, P. E., Schulenburg, Tex.
Patrick, D. R., Hagerman, N. Mex.
*Pearsall & Co., Utica, Ohio.
People's Gas Company, Tradesmen's Building, Pittsburg, Pa.
Philadelphia Company, Philadelphia Building, Pittsburg, Pa.
*Phillips, A. P., 314 North Main street, Findlay, Ohio.
Phillips, Jake, Springville, Utah.
Pinchin, Job, Salt Lake City, Utah.
Poland, C. E., Hagerman, N. Mex.
Pond, Chester H., Moorhead, Miss.
Prairie Oil and Gas Company, Neodesha, Kans.
Preston, John, 322 Washington Trust Building, Washington, Pa.
*Pursell, F. U., Waukena, Cal.
*Pursell, T. A., Waukena, Tulare County, Cal.
Pyle, P. L., Fort Gibson, Ind. T.
Ratliff, W. E., McMillan, N. Mex.
*Reardon, H. A., driller for F. S. Black, Delmont, Pa.
*Reed, Jefferson J., driller for R. D. Mead & Co., Higbee, Greene County, Pa.
Reese & Heasley, Waynesburg, Pa.
Reeves, Ira L., Muscogee, Ind. T.
*Ridpath & Potter, 587 Bourse Building, Philadelphia, Pa.
*Robbins, S. L., Blaine, Kans.
*Roberson, Elmer A., Box 83, Cheney, Kans.
Ross, Tim, Waynesburg, Pa.
*Roughen, Patrick, 213 Amory street, Fond du Lac, Wis.
*St. Marys Drilling Company, St. Marys, Ohio.
*Sealy, W. F., 27 Seventh street, Fond du Lac, Wis.
*Shanks, Oscar, P. O. Box 485, Alexandria, La.

*Sharpe, J. E., 304 West College street, Albert Lea, Minn.
Shay, John W., 249 Locust avenue, Washington, Pa.
*Shute, C. E., Bath, Me.
Smith, A. B., Muscogee, Ind. T.
Southern Pacific Railroad Engineering Department.
South Penn Oil Company, 323 Fourth avenue, Pittsburg, Pa.
Steele, C. L., Muscogee, Ind. T.
*Steinsiek, H. W., 4321 Prairie avenue, St. Louis, Mo.
Stevenson, J. B., Springville, Utah.
*Stotthoff Brothers, Flemington, N. J.
*Strait, E. C., Prentiss Vale, Pa.
*Sutter, Frank, Pensacola, Fla.
*Sutter, John A., Pass Christian, Miss.
Taylor, D. J., Roswell, N. Mex.
*Taylor, Fred, Grandville, Mich.
*Teeter, W. G., North Salem avenue, Dayton, Ohio.
*Thorne, W. L., & Co., Whitewater, Wis.
*Tomlin, James, Mars, Oreg.
*Tracy, Albert, Orrville, Ohio.
*Trow, Linden C., driller for W. J. Miller's Sons, Genoa Junction, Wis.
Turner, E. F., Leland, Miss.
*Vandervort, E. R., Warrens, Wis.
*Wainright, V., Lake Charles, La.
*Walters, W. P., driller for St. Mary's Drilling Company, Alto, Ind.
*Wankel, Frank, 535 Himrod street, Brooklyn, N. Y.
*Waterman Brothers, Hamorton, Chester County, Pa.
*Watkins & Co., Vancamp, W. Va.
*Weiler Brothers, Box 367, Marietta, Ohio.
Westfal, John, Provo City, Utah.
Westphal, Gus, Salt Lake City, Utah.
White, Elza, Roswell, N. Mex.
Willetts, Elmer E., 186 South Main street, Washington, Pa.
*Winger, Josiah G., Box 135, Grand Valley, Pa.
Yager, Frank, Salt Lake City, Utah.

In addition to the drillers furnishing records and samples, special thanks are due to the owners of many wells, through whose courtesy and by whose orders many of the samples and records were furnished the Survey. The names of the owners are given in the tables of records, those furnishing records being indicated by the letter "O" in the column headed "Authority."

OBJECTS, DEVELOPMENT, AND RESULTS OF THE WORK OF COLLECTING WELL RECORDS AND SAMPLES.

By MYRON L. FULLER.

The information relating to borings must generally be gathered when the well is being sunk or not at all. Many drillers keep records when the work is going on, but in the majority of cases these are soon lost. If the driller continues work in a single locality he soon comes to know perfectly the main points of the succession of the rocks and keeps no records, often even throwing away his earlier ones. In other cases he may remove to other regions, and, having no further personal interest in the original locality, the early records are lost or destroyed. Only the larger operators keep permanent records of their wells. For these reasons the effort is now being made by the Survey to secure the record at the time of drilling and to supplement it wherever possible by actual samples, which will be filed and made permanently accessible for use whenever questions arise regarding the materials encountered.

IMPORTANCE OF ACCURATE WELL RECORDS.

The knowledge of conditions beneath the surface, whether sought by the driller, the mining engineer, or the geologist, must be obtained either from surface observations of rock outcrops or from artificial sections afforded by mine or other shafts, inclines, tunnels, and borings. By systematic observations upon the character of the rocks over extended areas and the determinations of their inclination (dip) and their line of outcrop on level surfaces (strike), the trained observer is able to calculate more or less accurately the thickness of the beds, their depth below the surface, their structure, and to a certain extent their character as regards the occurrence of gas, oil, brine, or fresh water, especially the latter. The thickness and composition of rocks, even of the same bed, are not constant, but undergo changes, often considerable in amount and taking place within short distances. These changes are frequently of great importance in their effect upon the occurrence of the products named. Where the rocks are at the surface the changes can be easily recognized, but when below the surface only

the shaft or drill can determine the occurrence and nature of the changes in question.

The shaft is of immense value in restricted areas, but it is the widely distributed and often deep borings that afford information in regard to the broader features of interest to the driller, to the operator in search of oil, gas, or brines, and to manufacturers and others seeking artesian waters.

The importance of accurate records of borings was early recognized by the more enterprising of the drillers and by certain companies operating in oil and gas, and the success of such drillers and operators has been to a considerable extent due to their recognition of the importance of the precise information afforded by the borings, their insistence that records be kept, and their attention to other similar details, minor in themselves but often sufficiently important in the aggregate to make the difference between failure and success. It is probable that there is now not one successful operator on a large scale who does not require the keeping of at least partial records.

Among the many ways in which well records are of value the following may be mentioned: To the oil and gas driller they furnish information as to (1) the best point for locating the well, (2) the depth of the supposed productive bed, (3) the character of the material to be penetrated, (4) the amount of water which will be encountered, (5) the amount of casing required, and (6) the limit of depth to which it is desirable to drill. To the owners of such wells information as to each of the foregoing points, especially those affecting the cost of the wells, is furnished by the records, in addition to which data relating to still more important factors, namely, those of quantity and quality of supplies, are furnished. In the case of drillers and owners of water wells the same information is supplied, but here the items affecting the cost are of increased importance owing to the lower value of the product, and questions of head, quantity, and quality of supply again come to the fore. To prospective owners records show the results obtained by others and the probabilities of success of new ventures, while to the geologist they are of value in assisting him to a more thorough understanding of the geology, which in turn enables him to more intelligently answer the numerous questions constantly referred to him by drillers, well owners, and others.

A more detailed statement concerning the uses of records is given in the following paragraphs, with the view of presenting their benefits more fully to those drillers and owners, especially the smaller operators, who do not have the facilities of the larger companies for collecting and preserving their own records, but who by furnishing information can assist the Survey to a knowledge of the various regions, and thus enable it in turn to give them the benefit of the results of the studies of its geologists.

VALUE OF WELL RECORDS TO THE DRILLER FOR OIL AND GAS.

The contractor or driller for oil or gas is often called upon to sink wells in regions wholly unfamiliar to him. Among the questions which will arise are the following: (1) What is the depth of the supposed oil- or gas-bearing rock? (2) What is the character of material to be penetrated before reaching it? (3) At what depths, in what amounts, and of what quality can water for the boilers be obtained? (4) What is the depth of water seams which must be cased off? (5) What are the character, depth, and thickness of rock which will require casing to prevent caving, if any? (6) At what depth and in what rock is it advisable to stop drilling in case of failure to strike oil or gas at the expected point? (7) At what depths will minor shows of oil and gas be encountered? In case the contractor or driller is required to select the spot for drilling, another question will arise: (8) At what point is the structure most favorable for the occurrence of oil and gas?

A certain amount of this information can be obtained, as has been pointed out, by observation of the character, dip, and strike of the rocks exposed at the surface. Other data, especially those relating to the occurrence of water, to caving rock, and to the depth at which it is advisable to stop drilling, are best derived from records of borings. These need not, however, be necessarily in the immediate vicinity, for a geologist or a driller with a practical working knowledge of the simpler principles of geology can combine the observations afforded by surface outcrops with records of borings at a distance, and intelligently predict the conditions in the intervening area.

Depth of productive rock.—The depth to the productive rock is of great importance as affecting the success of a well. For a shallow well a relatively light outfit can be used, but for deeper borings heavy and more costly machinery and rigs are required. These, with increased cost of fuel, outfit, casing, and greater difficulty of manipulation, make the cost of a well increase rapidly with depth. The amount of oil or gas which would give a good profit on the investment required for a 1,000-foot well might not be sufficient to warrant the sinking of a 3,000-foot well.

It is apparent, therefore, that as close an estimate of the depth as possible should be made before starting to drill. This may in some cases be determined more or less satisfactorily by observation of the distance of the well from the outcrop of the rock and determination of the direction and amount of the dips at the outcrop and in the area intervening between it and the well, but in many instances the outcrop is several score, if not hundreds, of miles from the well, and there are many irregularities of dip and changes of thickness of the rocks in the intervening area, all of which serve to make computations from surface data difficult and unreliable.

On the other hand, deep drilling has been so extensively conducted in this country, especially in the East, that there are very few regions of any extent that do not have one or more deep borings. These furnish, where the data have been preserved, our best evidence of underground conditions, and, combined with surface observations, form a basis for predicting the materials to be encountered in new borings. Where there are a number of borings they afford accurate data for the calculation of dip, which as determining structure becomes an all-important factor in oil and gas operations. This is an especially important feature in regions where, as in much of Ohio, the rocks are buried by hundreds of feet of drift and are nowhere exposed to view at the surface. Two wells of known elevations and penetrating a bed at known depths are sufficient to establish the dip in such regions with greater accuracy than if outcrops were present and served as a basis for the determination. With distances and the amount and direction of dip known the depth can, as has already been indicated, be readily predicted at a given point. Without borings this would often be impossible.

Character of material.—Of almost as much importance as the depth of a well is the character of the material penetrated. On it depends the nature of the process of drilling employed. In the soft material of the Coastal Plain, as in parts of Alabama, Mississippi, and Louisiana, driving, jet, and rotary processes, either singly or in combination, are used, but none of these are suitable for rock work. If, therefore, a very hard bed is to be penetrated another type of outfit must be provided. The character of the tools and the rig itself must also be adapted to the nature of the material to be penetrated. In rock the rate of drilling varies from a few inches in the harder limestones to over 100 feet a day in certain shales; hence, in contracting for a well, knowledge of the character of the various beds and of their thickness is of the greatest value.

As already intimated, important variations in the character and thickness of the beds may take place underground without there being at the surface any evidence of the changes, and while it is possible to judge, to a certain extent, of the character of the beds beneath the surface from their more or less distant outcrops, by far the most accurate information is that afforded by the borings in the same or adjacent regions.

Water supplies.—When wells are located in valleys, or in thickly settled districts, water for boiler use can usually be obtained from streams or the wells of near-by houses. In many of the oil fields, where the wells are frequently located upon the sides or tops of hills or mountains, the question of boiler supplies is important, and small, separate wells are often drilled for this supply. Beyond the ability of the rock to hold water, as indicated by its texture, little is shown by

the surface outcrop. Nothing as to crevices, joints, local sandy beds, etc., on which so much depends, is indicated. All this can be finally determined only by the drill. In this case a single boring, unless in the immediate vicinity of the proposed new well, will not afford an absolute indication of the conditions, but from a considerable number sunk in the same kind of rock an average is obtained which shows the predominating conditions characterizing the bed. This is especially true of the quality of the water, which will vary greatly in different localities, often without any reference to conditions discoverable at the surface.

Casing off water.—Among the factors affecting the sinking of a well is the occurrence of water in quantities necessitating casing it off. This is of importance in determining the amount of casing necessary and its cost, and in determining the size of the original hole in case it is anticipated that several horizons at some distance from one another, each of which may involve a reduction of the size of the casing, will be encountered. As in the case of the water supplies discussed in the preceding paragraph, the most satisfactory information is that furnished by the records of adjacent wells.

Casing off "cave" rock.—In many of the older wells in the softer rocks, especially in shales, much trouble was experienced by the walls of the hole caving and stopping up the bore. This difficulty will be recalled by those familiar with the history of the old Dunkard Creek field, in southwestern Pennsylvania, where many of the wells sunk without casing were ruined by the caving of the walls. Even now that the caving is easily preventable by proper casing, a knowledge of the depths and thicknesses of troublesome beds is of importance in determining in advance the questions relating to casing and its effect on the cost of the well. This information is best furnished by records, as in the case of the water horizons already discussed.

Limits of depth.—Nothing can be further from the truth than the common fallacy that oil, gas, water, or whatever the driller may be in search of, can be had if the hole is only drilled deep enough. In unaltered porous rocks oil and gas may occur, within certain limits, regardless of depth; but all rocks, of whatever character, if buried deep enough, especially if subjected to the powerful compression incident to the formation of mountains, become altered through the influence of heat and pressure, often into more or less crystalline masses. In such rocks the volatile substances, such as the hydrocarbons, are expelled and it is useless to look in them for deposits of oil or gas. It is also useless to seek for oil in rocks of igneous origin—that is, those which have once been molten—for the conditions of their formation are such as to preclude the formation or retention of oil or similar substances. Nevertheless, wells have not infrequently been

sunk into such rocks in search of oil, but the uselessness of this is apparent to those who have noted the records of similar wells elsewhere, as well as to geologists and others who understand the nature of the rocks. The value of accurate records in indicating the depth at which it is advisable to stop drilling will be manifest in those cases where altered or igneous rocks, as described above, are encountered, and in general the logs of the deeper borings are of great value in showing the conditions to be expected at great depths.

Oil and gas shows.—In drilling, especially where the well is being sunk to a known producing sand, small shows of oil or a little gas are often encountered and passed through without much attention being paid to them. Probably many instances have occurred where valuable flows have been cased off, but one or two examples will suffice. In the region southwest of Olean, N. Y., on the outskirts of the Bradford oil field, the early wells were all sunk to the Bradford sand, at a depth of 1,000 feet or so below the valleys. In some instances shows of oil were noted at a certain depth, but were cased off without it being suspected that a producing sand was present above the Bradford. Later, when the Bradford supplies ran low, it was shown that the sand at the upper oil show could be developed into a producer, now known as the Chipmunk sand. Where accurate records had been preserved, the casing of the old wells was locally removed and both sands drawn upon; but where because of lack of records this could not be done, new wells had to be sunk, at an aggregate cost of many thousands of dollars. Similarly, in the Bellevernon and other gas fields in southwestern Pennsylvania gas flows which would now be of great value were cased off in the old days of high pressure. Where accurate records have been kept, these can be utilized by removing the casing in the old wells, but otherwise new wells must be drilled.

Structure.—It has been many years since the anticlinal theory of oil and gas was proposed. This theory postulated the axis of the anticline or crest of the rock arch as the most favorable point for the occurrence of gas, while oil and salt water should be successively encountered in going outward from the crest. While all anticlines do not afford oil or gas, and while oil is often found under somewhat different conditions, as at the point just above where a steep dip changes to flat (at the top of the rock step, as it were), the general principle involved in the theory has not been affected. On the contrary, almost every district, when closely investigated, is shown to agree with these principles, so that at the present time the problems of rock structure are as important as they ever have been in the history of drilling for oil and gas. In no way can the structure be determined so satisfactorily and with such accuracy as by wells or boring records.

VALUE OF RECORDS TO OWNERS OF OIL AND GAS WELLS.

The statements which have been made in regard to the benefit of accurate records to drillers for oil and gas apply with added force to the owners of wells, for the ultimate cost of the wells must, in nearly every instance, fall upon them rather than upon the drillers or contractors. The structure, as determining the most favorable points for drilling, the depth of the producing rock, the character of the materials to be penetrated, the available water supplies, the casing required to shut off undesirable water and to support "cave" rock, and the supply obtainable are all of the greatest importance in determining the success or failure of a well. As has been pointed out, this information is best afforded by records of adjacent wells, and the operator will practically always make inquiries in regard to adjacent wells before beginning his own. Frequently these wells will be found to have been drilled many years ago and the records lost. It is to prevent such loss and, instead, to make the information permanently available that the work of collecting records and samples has been undertaken by the Survey.

VALUE OF RECORDS TO DRILLERS OR OWNERS OF WATER WELLS.

In the same way that records are of value to oil and gas operators they are of benefit to drillers or owners of water wells. The question of the depth of the water-bearing rock, for instance, is of even greater importance than that of the oil or gas sands, because of the relatively low value of the water as compared with oil or gas. With crude petroleum at $1.50 a barrel a supply of only a few barrels a day will give a profit on the investment required for a well of 2,000 or more feet deep, while many hundred barrels of water are required to make even a much shallower well profitable. Moreover, for many manufacturing uses the supply must reach a certain minimum, representing the amount needed for the processes involved, in order to be of any value whatever, while oil, if present in quantities greater than a mere show, can generally be successfully utilized.

The great importance of obtaining water supplies at a moderate depth will be seen when it is remembered that among the competitors of any manufacturing establishment there will always be some who will be able to obtain abundant supplies of the best quality at almost no cost above that of pumping. In such instances the success or failure of an enterprise may depend on obtaining good water at a slight depth. The character of the material to be penetrated and the amount of casing are prominent items in the cost and, therefore, largely determine the success or failure of a well. Other elements, such as head,

volume, permanency, and quality of the supply, become of great importance, for on them depend the uses to which it may be put.

Upon the head, for instance, depends the height to which the water will rise, thus determining whether or not pumping, with its attendant expense for outfit, fuel, and labor, will be necessary, while the obtaining of water in sufficient volume, or of a certain quality, may, as has been pointed out above, determine the ability of a manufacturer to cope with competitors, or even the very existence of an industry in a given locality. The probability of success can, in many instances, be foretold in advance where records in surrounding regions are available. The importance of this knowledge has been long appreciated by those interested in obtaining supplies for industrial purposes or for the boilers of manufacturing establishments or railroad locomotives.

Wells have for many years been of great importance as a source of water for irrigation at many points in the West, and recently they have been extensively utilized in the cultivation of rice in Louisiana and other States of the Gulf and Atlantic coastal plains. In such regions the information and records afforded by the pioneer wells as to the depth and cost of wells, quantity and quality of water, etc., have likewise proved of much value.

Another important class of people benefited are those interested in the development of mineral waters for bathing, sanitariums, and resorts, or for the purposes of bottling for table or medicinal uses. The depths, quantity, composition, and temperature are all most satisfactorily afforded by records supplemented by the analyses which are usually made soon after the well is completed and which, like the records, are often soon lost.

Records of adjacent wells may, in cases, be of great benefit, especially to owners in furnishing a check on statements as to the occurrence of water horizons, depth to rock, amount of casing, total depth of well, etc., all of which are sometimes misstated when contracts have been let for a specified sum per foot or which have been inaccurately reported because of failure to keep proper records. They also afford a basis of comparison as to conditions with more successful or less successful wells of the locality, and frequently give a clue to the cause of failure or of variations from the normal wells.

In many regions the surface wells gradually fail because of the deforesting of the land or its drainage by ditches, and it may become necessary to sink deep into the rock for a permanent supply. All rocks do not yield water, while in some yielding abundant supplies the water carries too much mineral matter for ordinary use. It is in such regions that records, affording a basis for predicting results, are of special value.

IMPORTANCE OF RECORDS TO GEOLOGISTS.

To the geologist records are of value from both the practical and the scientific standpoints. Problems are submitted almost daily by drillers and by present or prospective well owners in regard to the occurrence of oil, gas, or water. Where he can visit the field he can, as already indicated, work out the general features of structure and character and thickness of beds, and can make certain generalizations as to the occurrence of water and in some cases of oil and gas; but he can not give more precise information without a knowledge of the changes which the beds undergo beneath the surface, and these are best afforded by well sections.

The occurrence of oil and gas is shown, as accurate investigation proceeds, to be more and more dependent upon structure, which term is here used in a broad sense to include both the attitude of the rocks and the changes in extent, thickness, or texture which they may undergo from point to point, and the same holds to an even greater extent in regard to artesian waters. Combining well records with surface observations, the geologist is able to locate the anticlines, synclines, flats, etc., so important in their bearing on the occurrence of oil and gas, to determine similar structures governing the occurrence of artesian waters and regulating their head, to predict the character of the material to be penetrated, to fix the depth of the producing horizon, and in the case of water to estimate the approximate volume to be obtained.

From the scientific standpoint records and samples, especially where the latter include fossils, aid the geologist to a better understanding of the age and succession of the rocks, assist him in the correlation of identical or equivalent beds in remote localities, and enable him to work out the details of structure and history, all of which furnish a basis for conclusions which are of much benefit to the driller or well owner.

WORK OF COLLECTING WELL RECORDS AND SAMPLES.

ORGANIZATION.

EARLY COLLECTION OF RECORDS.

Ever since the organization of the Survey the collection of records as an aid to the study of geology has formed an incidental part of the work of the geologist in the field, but since the beginning of the precise stratigraphic and structural work of recent years the collection of records has become an important part of the Survey's work in certain regions. The vast majority of wells, especially in Pennsylvania, were sunk a number of years ago, but fortunately many records have been preserved. These were carefully collected by the geologists in the individual localities.

PROPOSED SECTION OF OIL AND GAS (1902).

The collection of records finally became so important that it was thought that a section, organized for the purpose of collecting them in connection with a study of the oil and gas fields, might be organized to advantage, and an outline plan for such a section was, at the request of Mr. M. R. Campbell, submitted to the geologist in charge of geology April 28, 1902, by the present writer. The following is an extract from this plan:

In the prosecution of the work of areal mapping, and in the determination of the structure of the areas surveyed by Mr. [M. R.] Campbell and members of his party in Pennsylvania and Indiana, it has become apparent that great importance is to be attached to the information which may be derived from the deep borings for oil and gas.

As has been pointed out by Mr. Campbell, it is generally only in increased details of outcrop, made possible by accurate topographic maps, and more especially in the greater refinement in structural details, that improvement has been made upon the detailed work of the earlier surveys in the region mentioned. Engineers, coal operators, and oil and gas men with whom the geologists have come in contact and who have learned of the nature of the structural work which is now being undertaken, have almost invariably shown a marked interest in what is being accomplished and have fully appreciated its value to them as practical men.

Already many errors, some of them very grave, have been found in the structural work of the Second Survey of Pennsylvania. Supposedly continuous folds have been found in reality to consist of a series of short disconnected ellipsoid domes and canoe-shaped troughs, and marked by frequent irregularities and by noticeable offsets at their terminations. Others have been shown to vary at angles as high as 60° or more from the positions previously determined, and, in fact, everywhere abound in unsuspected relations. The once famous oil fields west and northwest of Bradys Bend on the Allegheny River have previously been thought to have no relation to structure, but have now been proved to have a very close and definite relation to it, a fact that should be of great value in the drilling for the Speechley oil sand which is now going on, and in the drilling of gas wells, which, following the recent revival of activity, are fast becoming of great importance in this and other regions.

The determination of the minor but important details of structure is dependent (1) upon information afforded by mines, (2) upon observation and correlation of natural outcrops, and (3) upon information afforded by deep wells. The first is available only in synclines containing workable coals. The second is of little value in many localities because of the general absence of distinctive characteristics over broad areas and through considerable vertical ranges of the Devonian and Carboniferous rocks, not only in Pennsylvania and Indiana, but in many other of the areas where these rocks occur. In such regions the oil and gas wells have frequently furnished the only reliable data for the determination of the structural details.

The growing disposition on the part of the States to cooperate with the United States Geological Survey makes it somewhat probable that work similar to that now going on in Pennsylvania will at no very distant date be undertaken at other points, where presumably similar conditions will prevail and similar results be expected and required.

The great value of well records in his work in Pennsylvania was fully appreciated by Mr. Campbell, and considerable amounts of time were devoted both by him and by myself to the collection of such records. Some 1,500 were obtained in 1901. It has become apparent, however, that to carry out the collection of records to the

extent desirable, and especially to properly file and catalogue them so as to be readily available, is impracticable with the present force. This, in addition to the advisability of collecting and publishing this information (which seems likely to be of considerable economic value), has led Mr. Campbell to suggest to me that I place before you the question as to the advisability of employing or assigning some geologist or other person who can devote the whole or a large part of his time to the work, and who should be given charge, under your supervision, of the work relating to oil and gas.

Some of the duties that might be expected to devolve, in whole or in part, upon an assistant geologist or geologist in charge of oil and gas are as follows:

1. To consult with other geologists and with hydrographers and topographers with the view of collecting and filing information relating to deep borings for oil and gas obtained by the various field parties of the Survey.

2. To obtain representative records and information as to structure of all pools as far as possible.

3. To collect and file samples of oil- and gas-bearing rocks, together with other characteristic beds encountered, as far as feasible.

4. To gather together published records and all available unpublished records as far as practicable, and to file them in the form of card catalogues which will be available to the members of the Survey at all times.

5. To prepare a bibliography of all oil and gas papers which have appeared in scientific publications and, as far as practicable, those which have appeared in trade journals up to and including 1900.

6. To keep a bibliographic catalogue of all oil and gas papers which have appeared since 1900 in both scientific and trade journals.

7. To review oil and gas periodicals and to keep records of developments and progress.

8. To keep a general index map showing the location of the oil and gas fields throughout the United States.

9. To keep State or county maps or topographic maps of the Survey, where available, to show the details of the various fields and pools of oil and gas.

10. To prepare geologic columnar sections for each pool as far as possible.

11. To prepare digests of structure for each pool as far as possible.

12. To keep a catalogue of all sands and their character and geologic positions as far as known.

13. To prepare correlation tables of the various sands where the information is available.

14. To visit new fields and investigate the geology and determine the structure, running levels where necessary.

15. To visit, collect records, and prepare reports on the oil and gas in quadrangles and districts where it is not practicable for the geologist in charge to give his personal attention to the problem.

16. To furnish other geologists with all information as to stratigraphy, structure, etc., which is afforded by the samples and by the records and other information on file.

17. To answer inquiries of operators, etc., regarding structure and other points relating to oil and gas as far as possible, without divulging confidential information.

18. To publish immediately in trade journals summaries of the geological knowledge of the regions of newly discovered pools.

19. To publish in Survey publications from time to time detailed reports of the development, structure, and general geology of new pools or the extensions of old pools.

20. To prepare statistics on production, etc., for the Mineral Resources, if required.

To summarize, the appointment or assignment of a geologist to take charge of the

oil and gas problems would create a sort of "bureau of information" which would be of much value to both the operator and the geologist.

The gas production is greater now than at any time in the past, and the oil production is holding its ground fairly satisfactorily. It seems likely, therefore, that there will be steady demand for information for some time to come, and it is not unlikely that an "oil and gas division" could be made a division of some importance in the Survey.

ORGANIZATION OF THE "WELL DIVISION."

The lack of available funds made it impossible to take up the plan as a part of the work of the geologic branch at that time, but in November of the same year a memorandum embodying a plan for a proposed "well division" was submitted to the Director by Mr. F. H. Newell. Under this plan it was proposed to organize in the hydrographic branch a division of work devoted to wells and ground waters, which should be under the charge of a geologist designated "chief of the well division," under whom would be two assistant chiefs, one for the eastern part of the country and the other for the western part, including the sixteen reclamation States and Territories. It was expected that each would spend at least four months of the year in the Washington office, so that one geologist would be constantly on duty to attend to administrative work and correspondence. It was proposed to give particular attention to a card catalogue of wells and to the compilation and filing of schedules relating to wells, which should include those drilled for oil and gas as well as for water. The catalogue and other data were to be available to the entire Survey, and the officers of the division were to supply information to drillers and others requesting it. In addition to the regular geologists, it was planned to have an assistant in each State to visit wells, study the stratigraphy, collect general information, and prepare detailed reports on the geology in its relation to the water resources, the results of which were to be published annually in progress reports, or as separate water-supply papers in the case of completed studies.

The memorandum of Mr. Newell was referred to Dr. C. W. Hayes, geologist in charge of geology, who, in a letter to the Director dated November 18, 1902, expressed his agreement with Mr. Newell as to the necessity of such an organized effort to systematically secure the records of wells being drilled for various purposes throughout the country, but questioned the desirability of placing one man in charge of the entire work. Instead, a recommendation was made that two geologists be employed, one to be placed in charge of the eastern section and the other in charge of the western. It was proposed that the general supervision of the work and of the scientific portions relating to water should rest with the hydrographic branch, while the portions relating to geology should be under the similar supervision of the geologic branch.

The letter contained a recommendation that the present writer be assigned to the charge of the eastern section, which assignment was made by the Director on December 23. To Mr. N. H. Darton was assigned the charge of the western section.

WORK OF THE DIVISION OF HYDROLOGY IN 1903.

The designation of "well division," later gave place to that of "division of hydrology," but without change of scope of work. Plans for collecting well records were taken up immediately on the organization of the division. As has been indicated, it was originally intended to include the collection of oil and gas records with those of water, but because of lack of available funds and proper assistance it was necessary to confine attention entirely to water. For use in connection with the collection of well data, forms for mailing to well owners and cards for filing the information were prepared. The form for mailing has been slightly modified from time to time. The form now used is as follows:

SIR: In its study of the water resources of the United States, which this Survey is making with the view of publishing the results for the benefit of the people, an attempt is being made to obtain important facts relating to wells, whether flowing or not. As it is impracticable on account of expense to visit all places, the endeavor is made to extend and complete the information by correspondence. If you will aid in this work by furnishing the data requested in the following list of questions your assistance will be much appreciated. If you can not supply all the data, kindly answer such of the questions as you can, a partial report being much better than none.

The following inquiry blank is on the same form with the above letter:

1. Well is in.....County. The nearest post-office is.....
   Distance of well from post-office..... (Miles.) Direction from post-office.....
   Locate by section if public-land surveys exist: Township....., Range.....,
   Section....., Quarter.....
   If in town, give street and number.....
2. Owner ..... Address.....
3. Driller ..... Address .....
4. Situation of well..... (Hill, slope, plain, valley.) Elevation is.....feet.....the (Above or below.)
   level of ..... (Sea, railroad station, lake, river.)
5. Type of well..... (Dug, driven, bored, or drilled.) Year completed..... Diameter at
   top..... At bottom .....
6. Depth of well..... Does it enter rock?..... If so, at what depth?.....
7. Depth to principal water bed..... Character of
   water bed ..... (Gravel, sand, clay, rock, etc. If rock, state kind.)
8. Were any other water beds or seams found?..... If so, give depth of each.....
9. Give sizes and lengths of casing.....

10. Does water flow at surface without pumping?..... If so, at what height does it now flow?.....
Has it been tested to see how high it will rise?..... If so, to what height?..... What is its pressure?.....
If not flowing, how near surface does it stand when highest?.....
When lowest?.....
11. Is well pumped?..... If so, by what .....
(Suction, deep well, or force pump, steam, gasoline, air-lift, or windmill.)
12. Temperature of water at well mouth..... Month taken.....
Temperature at bottom ....
13. Natural yield, if flowing..... (Gals. per min.) Maximum yield by pumping..... (Gals. per min.)
water is lowered.....feet by pumping. (State number.)
14. Has supply decreased or increased?..... To what due?.....
15. Is flow or clearness of water affected by storms, winds, etc.?..... If so, describe .....
16. Quality of water—hard, soft, salty, alkaline, iron, or sulphur bearing.....
Cost of well..... Of pumps.....
17. Is water used for drinking?..... Washing?..... Cooking?.....
Stock?..... Manufacturing?..... Irrigation?.....
If for manufacturing uses, state nature..... If for irrigation, give crops .....
If used for public supply, give number of buildings and people supplied:
Buildings..... People.....
Is it sold?..... If so, for what purposes?..... .....
If used for purposes not mentioned, please name.....
18. Describe interesting peculiarities of well, if any, on back of this sheet.....
19. Give record of beds passed through, analysis of water, names of other well owners or drillers on back.
Name of person filling out blank .....

These or similar circulars were distributed in Maine, New Hampshire, Vermont, Rhode Island, Connecticut, New York, Georgia, Florida, Mississippi, Tennessee, Kentucky, Arkansas, Missouri, Iowa, Minnesota, Wisconsin, and Michigan, and a large number of records were obtained, of which about 2,750 were listed in Water-Supply and Irrigation Paper No. 102. The larger part of the records gave little information as to the strata penetrated, although a considerable number of detailed records were obtained from scattered localities and published in the paper mentioned. The circulars described are still largely used to obtain data relating to wells other than records of strata penetrated.

PRESENT ORGANIZATION OF THE WORK.

In the summer of 1903 it became necessary, in order to make fine distinctions in glacial materials on Long Island, New York, where the geology and water resources were under investigation, to collect samples from the wells being drilled on the island. This work of collecting samples was in charge of Mr. A. C. Veatch. The will-

ingness shown by operators and drillers to assist and the value of the material obtained suggested the organization of a similar system for the entire country.

Accordingly, during the fall of 1903, Mr. Veatch drew up an outline of a proposed system for collecting and preserving well samples, which was indorsed by the geologists interested in the keeping of records and samples, with the result that it was decided to take up the work as soon as circumstances should permit, which was at the beginning of the fiscal year 1904–5.

The plan outlined by Mr. Veatch for the collection of well records and samples contained many points in common with that for the proposed "oil and gas section," submitted by the present writer in 1902. (See pp. 28–39.) The principal points of difference are the inclusion of water wells in the present system and the exclusion of oil and gas data, except as they relate to stratigraphy and structure as shown by the well records. The items covered by paragraphs 1, 2, 3, 4, 7, 16, and 17 of the former plan are likewise covered by the present work, while it is hoped that in the future those mentioned in paragraphs 10, 11, and 14 will also be included.

As the plan originated in the division of hydrology the new work was assigned to it, about two-fifths of the expense being borne by the eastern section and the remainder shared equally by the western section of hydrology and the geologic branch. The oversight of the work rests with the chief of the eastern section, but its inauguration was placed in the hands of Mr. Veatch, assisted by Mr. E. F. Lines, by whom it was put into successful operation. On the relinquishment of the work by Mr. Veatch, who wished to take up more purely scientific problems, the prosecution devolved upon Mr. Lines, to whom much of the success of the work is due.

RESULTS.

The results obtained during the six months in which the system for collecting records and samples has been in operation are very gratifying. The practical nature of the plan has appealed to drillers and others interested in wells and has resulted in many offers of cooperation. The plan has likewise been cordially received by the press and favorably commented upon editorially.

In the office the plan has likewise been shown to be eminently practical. The system outlined by Mr. Veatch has now been in operation long enough to thoroughly test its efficiency, and has proved to be simple in operation, economical as to labor, convenient to handle, and effective in its results. A few minor changes have been found desirable, but in all its main features the plan followed is substantially as originally formulated.

The results of the work may be summarized as follows:

Approximate number of persons returning samples, 200.
Number of wells represented by complete sets of samples, 111.
Number of wells represented by incomplete sets of samples, 190.
Total number of samples received, 3,945.
Records received in Survey notebooks, 139.
Records received in other ways, 230.

The scientific results include detailed records from 111 wells. Of these nothing need be said, their character being indicated by the present report.

METHODS OF WORK.

A number of States have, as a part of their work, undertaken a more or less systematic collection of deep-well records. The Second Geological Survey of Pennsylvania especially gave great attention to this feature, employing several men on the work of collecting and tabulating well records, of which several thousand were published. In some cases observers selected by the State survey were stationed at certain important wells to insure the collection of samples and the taking of accurate measurements. A great number of well records have also been independently collected by geologists throughout the country for the information they throw on stratigraphic and other problems, and a considerable number of them have been published, often constituting contributions of great importance to those interested in the occurrence of oil, gas, brines, and potable waters. The present system of the United States Geological Survey is believed to be more extensive and comprehensive than any previously put in operation for the collection of well records and samples, and it has been thought desirable to put on record a description of the plan, for the benefit of those persons or organizations who may desire to conduct similar work in the future.

It being manifestly impossible, because of the great expense involved, to place observers at the various wells, it was necessary to arrange for cooperation on the part of drillers throughout the country. This cooperation could in general be expected only when the drillers should be substantially benefited by the work, and consequently in the development of the plan this point was kept constantly in the foreground. Arrangements were made whereby such questions as the drillers should submit in regard to their work would be promptly attended to, and records interpreted or samples examined on request. In return the driller is requested to furnish written records of his wells and samples of materials penetrated, his assistance to be acknowledged in the reports on well records, issued annually.

GENERAL PLAN AND DETAILS OF WORK.

(FORMULATED BY A. C. VEATCH.)

The plan followed in the collection of well records and samples was developed by Mr. A. C. Veatch, assistant geologist, who also drew up the various forms used in correspondence, field, and office. The work may be summarized as follows:

First step is to obtain the names and addresses of drillers and well owners, who are informed of the advantages of saving samples and records and invited to cooperate. When a driller signifies his willingness to assist, he is supplied with notebooks for keeping the records, and small bags for shipping the samples through the mails free of cost. The receipt of all records or samples is acknowledged. If the original invitation to cooperate is not answered within a reasonable time, a second request is sent, which may be followed by others if necessary. An account is kept, by means of a card file, of letters and bags sent, and the records and samples are likewise systematically filed as received. At the end of each year, or oftener if the conditions demand, a report is to be prepared giving the names of persons cooperating, a summary of the wells reported, and complete records of the more important wells represented by samples or by detailed records.

SOURCES OF ADDRESSES OF DRILLERS AND WELL OWNERS.

One of the first steps in the work was to secure the names of drillers or owners of wells in process of drilling. These were obtained from the following sources: (1) City directories, gazetteers, etc., (2) parties voluntarily offering to cooperate, (3) trade and engineering publications, (4) geologists and others in the field, (5) newspaper clippings.

The city directories and gazetteers of drillers furnished the largest number of addresses, but as all classes of drillers, including many local operators, are there included the percentage volunteering to assist was small. Perhaps the most effective aid was secured through voluntary offers of assistance from drillers in response to a press notice describing the work which the Survey is undertaking in the collection of samples and records and asking for cooperation. This was widely published, often with favorable editorial comment, in engineering, oil, and water journals and in newspapers. A large number of addresses of drillers and owners were also secured from advertisements for bids, news notes on water supplies, etc., in the engineering and trade journals. The journals now consulted are as follows: Engineering News, Fire and Water Engineering, American Magazine of Mining and Investment, Pacific Oil Reporter, Petroleum Gazette, Oil Investors Journal, and the semiweekly Oil City Derrick. A single issue of a weekly magazine may furnish as high as ten or more addresses, and the

cooperation obtained through these addresses, especially through those obtained from advertisements for bids, is especially efficient. The newspapers throughout the country contain a vast amount of information relating to wells, but it has been found that this is not satisfactorily collected by the press-clipping bureaus, and at present little use can be made of it.

Filing of clippings.—The magazines are examined as received and clippings taken of advertisements for bids, news notes, etc. These, together with the clippings received through the press bureaus, are commonly pasted on a 4 by 6 inch card. At the top of this card is space for the name of the State, county, and town. If the clippings are long and require folding, an envelope attached to the face of the card, opening upward, is of much assistance in filing.

The clipping cards are marked with the name of the publication, and the volume, page, and date, after which they are filed by State, county, and locality. The clipping file gives not only addresses, but a comprehensive summary of drilling operations and allied subjects.

PREPARATION OF MAILING LIST.

Each name and address of a driller or well owner is entered on a 4 by 6 inch card, which also serves as a stock card. In addition to the spaces for the name and address there are spaces for recording the position (owner, contractor, foreman, driller, etc.) of the person referred to, the dates on which circular letters inviting cooperation were sent, the addresses to which supplies are sent, the number of notebooks and bags furnished, and the dates on which they were forwarded. The form of this card is shown below.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

Name, Position,

Permanent address, First circular sent,

Circulars sent.

Date.	Address.	N. B.	Account of bags sent.

ARRANGEMENTS FOR COOPERATION.

When the addresses are first recorded on the cards, a letter inviting cooperation is sent. The character of the letter varies with the person to whom it is addressed, but one or the other of two forms is commonly used. These are given below, the first being sent to drillers and the second to well owners.

Letter sent to drillers.

SIR: The demand for information regarding wells has become so great that the United States Geological Survey has decided to issue a yearly publication giving briefly an account of the wells bored in the preceding year. This report is to be published as near the beginning of each year as practicable, and will be sent to all who apply for it. It will contain the names and addresses of persons doing well work, and will summarize the work done by them in the preceding year.

In order that no portion of your work may be overlooked in this report, you are requested to inform this office from time to time of the progress of your work and to forward records and samples of the materials penetrated in your wells.

That the foreman of the outfit, or the person visiting the wells, may not be burdened with a great number of bulky bottles or cans and an ever-growing accumulation of samples, small canvas bags have been prepared (one of which is inclosed) in which samples may be transmitted through the mails without the payment of postage. As these samples can be mailed as often as the men visit the post-office, there is no danger that they will accumulate and become burdensome. For the keeping of a log a convenient pocket memorandum book has been prepared and will be sent with the sample bags.

In order to keep in touch with you and your foreman, a card like the inclosed will be mailed at stated intervals. This will not only serve as a reminder, but will save you some clerical labor.

This work should enlist your cooperation for the following reasons:

First. Your name and work will be kept before a class of readers interested in well drilling.

Second. Records of your work will be carefully filed in this office, and will be readily available to you at any time, so that in case your notes are lost they can be duplicated.

Third. You will aid materially in the study of the geological structure of the United States, a knowledge of which can not fail to benefit you as a well driller.

In some cases it will be necessary that the records should be regarded as confidential, and in these cases the information will be carefully guarded, and used only under the conditions which you stipulate.

I shall be glad to hear from you regarding this work and will be grateful to you for any suggestions.

Letter sent to well owners.

SIR: The Survey is making a systematic collection of well records and samples. Such data are of great assistance in the study of many of the problems which the Survey is called upon to investigate, and you are cordially invited to render assistance by sending to this office records and samples from the wells in which you are interested.

The results of this work, except in cases of confidential records, will appear in a yearly publication and in detailed reports of special areas, which will be prepared from time to time, copies of which will be sent to you.

If you will undertake to save samples, please sign and return the inclosed card, which requires no postage. A supply of canvas bags like the one inclosed will then

be sent you, in order that the samples may be transmitted through the mails without the payment of postage.

In some cases it is necessary that records be regarded as confidential, and in these cases the information will be carefully guarded and used only under the conditions which you stipulate.

When the first letter inviting cooperation is sent out the date is entered on the card (p. 29). If a reply is not received in two weeks or a month, it is often desirable to send out a second letter. In order to keep track of this correspondence, projecting metal clips of different colors are used. Thus, if the first circular is sent out on January 1, and it is desired to send a second letter on January 15, the date January 1 is entered on the line opposite "circulars sent," while the clip is placed on the number 15 at the top of the card. As the cards are of uniform size and fit closely into the drawer, all the clips for a given date fall in a single line, and it is easy to select the cards for a particular date without handling those relating to any other date. To assist still further in handling the correspondence, clips of the following colors are used for the different classes of cooperators: Copper for persons such as foremen for large firms saving samples by order of employers or others; white for all other persons saving samples; green for owners not saving samples, and steel-blue for drillers not saving samples.

If a reply is not received to the first letter by the end of two weeks, a second letter is sent, which is commonly as follows:

Second letter sent to drillers and well owners.

SIR: In order that the collection of well samples being made by this office may be as complete as possible, one of the inclosed forms is sent at stated intervals to all persons interested in well drilling.

If you will save samples of well borings for the Geological Survey, please fill out this card, which requires no postage, and return it to this office, when a supply of canvas bags, which will carry the samples through the mail without the payment of postage, will be sent you.

The card should also be filled out if you need additional sample bags or if you are about to move your outfit to a new place.

If a reply to the second letter is not received, the same form is sent again after an interval varying with the individual circumstances. By repetition the letter serves to impress the importance of the work upon persons not responding to the first invitation, with the result that cooperation is sometimes finally secured. The same letter is also sent from time to time to persons saving samples, in order to keep in touch with them, to make sure that the work is not forgotten, and that the necessary supplies are ordered as required.

With the original letter inviting cooperation and with the second letter there are inclosed a sample of the bags used for shipping samples and a franked card on which the recipient can designate the number of notebooks and bags required.

The sample bags are of light but strong canvas and measure 3½ by 5 inches. On them are printed the "penalty frank" and the Survey address. At the top is a string for securely tying in the contents before shipment.

When the card requesting supplies is received the supplies are immediately shipped, together with a notice of shipment.

TAKING OF NOTES AND SAMPLES.

Form of notebook used.—As every effort has been made to assist the driller in keeping notes and saving samples, special notebooks as well as sample bags were devised.

On the front cover of the notebooks now in use[a] is the title, and on the back cover are printed a postal frank and the address of the Survey, so that the book may be returned by mail without wrapping. Experience has shown that the books become much less soiled than was anticipated, little trouble being encountered in this line.

The inside of the front cover contains the following simple directions, prepared by Mr. Veatch:

Suggestions to drillers.

1. Samples should be taken from each bed passed through, and never more than 20 feet apart, even in the same bed.
2. Samples from wells in sands and clays should not be washed, as washed samples of sandy clay show only clean sand and give a wrong idea of the character of the bed.
3. All oyster, clam, or other fossil shells should be placed in the bags with the dirt or sand in which they are found and marked with the depth from which obtained.
4. Samples should be dry before being mailed.
5. A blank label will be found in each bag. After it is filled out it should be folded once to protect the writing.
6. Bags should be tied securely and mailed. They require no postage.
7. In the first two or three samples sent in, the "Location" should be filled out with care; in the succeeding samples so much care need not be taken with location, but the rest of the card should be complete.
8. Note depth and thickness of all water-bearing layers.
9. Note under "Remarks" the quality of the water from each layer, as hard, soft, salty, alkaline, or sulphur bearing.
10. Note height to which water from each layer rises in well, and give flow in gallons per minute.
11. Make frequent use of the "Remarks" column to explain your notes.
12. If you leave the rig, send in your notebook with the name of your successor and a new book will be sent to him.
13. If you do not understand what is wanted, or desire information on any point, write to this office, using one of the envelopes sent with the first shipment of bags. They require no postage.
14. It sometimes happens that unauthorized persons represent themselves as members of the Survey. If you desire to know whether a man is connected with the Survey, ask for his identification card, which is signed by the Secretary of the Interior and the Director of the Geological Survey.

[a] A new edition to be used after January 1 varies in a number of unessential particulars from the form here described.

Names of owners and drillers who furnish records and samples will appear in the annual publication of the Geological Survey on well borings.

The Survey desires to assist and cooperate with owners and drillers in every way possible, and will be glad to answer questions.

To assist the driller in identifying the rocks, in obtaining a correct understanding of simple geologic conditions, and in keeping more intelligent records, a few geologic notes and definitions of the more common types of rocks, based largely on notes by Mr. G. H. Eldridge, are printed on the inside of the back cover and on the page facing it, respectively. These are given below.

Geologic notes.

In a simple classification rocks may be grouped into three divisions: (1) Sedimentary, (2) metamorphic, and (3) igneous.

Sedimentary rocks.—Sedimentary rocks are formed of fragments worn from older rocks by the action of rain, wind, frost, etc. Such materials were carried by water or glaciers until deposited as beds of clay, sand, gravel, marl, etc. Other deposits consist largely of corals, or of shells, such as oysters and clams. When first deposited the materials are loose and unconsolidated, but they become gradually hardened and cemented together, especially when covered by later beds, and form solid rocks.

Metamorphic rocks.—Sedimentary rocks have frequently been subjected to heat and pressure, which has further hardened them, or even produced a crystalline texture. Sediments and igneous rocks so altered are known as metamorphic rocks. Mica-schist and marble are typical examples. They generally retain a bedded or foliated structure.

Igneous rocks.—Igneous rocks have come from the earth's interior in a molten state and have forced their way between other rocks or have overflowed as lava beds at the surface. They are nearly all more or less crystalline in texture.

Resemblance of rocks of different ages.—Rocks of the types indicated above occur the world over, those of one locality often being indistinguishable from those of another. Notwithstanding this, there may be a difference of thousands of years in age and a great variance in conditions of formation. It is not warrantable, therefore, to say that because a rock in California has the same composition as an oil-bearing rock in Ohio it is of the same age and will yield petroleum.

Fossils.—In sedimentary rocks remains of animals and plants are often found. These generally consist of portions or impressions of shells, skeletons, or leaves, and are known as fossils. A bed can frequently be recognized and its age determined by fossils. It is of great importance that all fossils be saved.

Definition of a formation.—A rock or succession of rocks possessing uniformity of character throughout a considerable area is termed a formation, and is given a name, such as Trenton limestone, etc. The importance of identifying these is great, and their identification will be much facilitated by the preservation of samples.

Structure.—When deposited, sedimentary beds are nearly horizontal. Subsequently they have often been thrown into inclined positions or bent into wave-like folds, the arches of which are known as *anticlines* and the troughs as *synclines*. When the beds are further disturbed they may become broken and the different parts displaced or *faulted* from their original position. The slope of the beds is known as the *dip*, and the direction in which they extend or would outcrop on a horizontal surface is known as the *strike*. The directions of strikes and dips are of importance in studying the occurrence of water and oil, and should be recorded whenever possible.

The definitions of rocks are as follows:

In order to assist the driller in keeping records, brief definitions of the more common rock terms are given below.

UNCONSOLIDATED DEPOSITS.

Soil and subsoil.—The weathered upper portions of any rocks.

Till.—An irregular mixture of clay, sand, and bowlders deposited by glaciers.

Alluvium.—Sand, clay, etc., deposited by streams.

Gravel, sand, and clay.—Made up respectively of pebbles, sand grains, and finer particles.

Chalk.—A soft, white earthy substance made up of fine particles of lime.

Marl.—A clayey substance containing much lime.

SEDIMENTARY ROCKS.

Sedimentary rocks are made up of fragments of older rocks. The fragments or grains are usually rounded, a feature which helps to distinguish them from igneous rocks.

Conglomerate.—Consolidated gravel.

Sandstone.—A consolidated sand. It is said to be *massive* if there are few bedding planes, and *shaly* if it splits into plates.

Quartzite.—A sandstone in which the spaces between the grains have filled with a hard cement (silica), forming an excessively hard rock.

Shale.—Consolidated clay; a soft, fine-grained rock which tends to split into thin plates (often improperly called soapstone).

Slate.—Like shale, but harder; splits into thin plates which may or may not coincide with the bedding. The tendency to split is not often recognized in drilling. Example: Roofing slate.

Limestone.—Formed from consolidated marly beds, or from beds of coral, shellfish, etc. It is composed mainly of carbonate of lime, but often contains sand and other impurities, and is often very hard. It can be most readily detected by the bubbling which takes place when it is touched with muriatic acid.

Flint, rock salt, gypsum, coal.—These are too well known to require definition.

Concretions.—Hardened lump-like masses within the rock, and should not be confounded with real bowlders.

METAMORPHIC AND IGNEOUS ROCKS.

These rocks are generally made up of angular crystals, often recognizable by their glistening faces, a feature which is not often possessed by the fragments of sedimentary rocks.

Marble and dolomite.—*Marble* is a crystalline limestone and gives the same reaction with acid as limestone, marl, and chalk. *Dolomite* resembles limestone, but the bubbling with acid takes place only when the acid is hot. In composition it differs from limestone and marble in that it contains carbonate of magnesium.

Soapstone or talc.—Fairly soft and greasy to the touch. It is seldom encountered in drilling, the substance called soapstone usually being a soft shale, although the name is sometimes incorrectly applied to clay or slate.

Schist.—A crystalline rock characterized by thin layers of mica or other mineral.

Gneiss.—A rock intermediate in character between schist and granite.

Granite.—A crystalline rock composed of quartz, feldspar, and other minerals.

Trap.—A very dark crystalline rock of igneous origin.

The first page of the notebook is used for a general record of the well. It is as follows:

Well record on first page of driller's notebook.

Well is located.....miles in a.....direction
from.....post-office, in the
.....¼ of.....¼ of Sec.....Twp.....Range.....
Owner.....
Contractor.....
Drillers.....
Well began....., 190.; completed ....., 190.
Rig used—cable, rotary, jet, or.....
Diameter of well: .....inches from.....ft. to.....ft.;
.....inches from.....ft. to.....ft.
Length of casing.....
Casing perforated or strainer inserted at.....ft.
Main water supply from .....ft.
Well pumps.....gals. per minute from depth of.....ft.
Well flows.....gals. per minute from depth of.....ft.
If flowing, what is the pressure?.....

Fill out for oil and gas wells.
- Pool or district.....
- Well No.....on.....farm.
- Amount of oil obtained.....
- Amount of gas obtained.....
- Name of sand.....

.....
.....
.....
Recorded by.....
Address .....

The notebook contains 7 double pages for the recording of data. It is an adaptation of a form used by Mr. M. R. Campbell for oil records, which in turn followed the general plan of the notebooks of the Second Geological Survey of Pennsylvania and of later surveys and corporations. On each double page are seven columns, headed as follows: "Sample No.," "Rock or material," "Color," "Hard or soft," "From—," "To—," "Remarks."

Taking and forwarding samples.—In taking, preparing, and shipping samples the suggestions in the notebooks are generally followed fairly closely. The samples are commonly taken every 10 feet, or at every change of material, dried on a board or otherwise,

and then placed in the bags. With each sample is included a 2 by 3 inch label, on which the following data are given by the driller: Sample number, location, name of owner, driller, and person sending sample, and the depth at which the sample was obtained.

EXAMINATION AND FILING OF SAMPLES.

Transfer to bottles.—When received at the office the samples are transferred to glass bottles. The bottles now in general use are approximately 2¾ inches long and three-fourths inch in diameter.

Glass jars, measuring 3 by 1¾ inches, with a tin cover screwing on the top, were originally used, but they were found to be larger than necessary in most cases, although they are convenient where fragments are blown out in shooting or where fossils or pebbles are brought up.

Acknowledgment of samples.—When the bags are opened the labels are examined and acknowledgment is made to the persons sending them.

EXAMINATION OF SAMPLES AND FILING OF RECORDS.

Whenever a set of samples from a particular well is complete it may be taken from the temporary files and referred to a geologist for examination and identification. The data thus obtained, together with those afforded by the drillers' notebook, are then compiled on cards. At the top of these cards are spaces for the names of State, county, and town in which the sample was obtained, for the names of the owner and driller of the well and of the person sending the samples, and for the dates of opening and closing the account. Below this space for general information are seven columns, which contain the following headings: "Date," "No.," "Character of strata," "From—," "To—," "Drawer No.," "Date." If the record is long, supplementary cards are used. These are ruled as described above, but at the top there are spaces for only the names of the State, county, and town.

Data of economic value are recorded on a separate card. The various cards, together with clippings, notebooks, etc., relating to the same well are then fastened together by a clip and filed by locality.

STORAGE OF SAMPLES.

Importance of preservation of samples.—Mr. A. C. Veatch urged the general preservation of samples, as descriptions even by the best geologists are seldom as satisfactory as the samples themselves. Because of advances in geologic science and of later and more precise data for discriminating the characters of underground beds, peculiarities which had been entirely overlooked or misinterpreted often become clear as a result of a later examination. Many facts of value,

both to science and to the practical driller, would undoubtedly be lost if the samples were discarded as soon as examined. Of course, certain simple types of sandstones, shales, and limestones can be described with a considerable degree of accuracy, and such samples, together with duplicates from the same bed, can be discarded, but the present policy is to preserve everything that can possibly be of value.

Labeling of sample bottles.—When the samples are transferred to the bottles a label is made out from the field label which accompanies the sample. It is printed on gummed paper, so that it may be easily attached to the bottle, and on it are written the well and sample number, depth, date, location, and name of owner.

Temporary files.—The samples frequently come in one or two at a time, and it is generally desirable to postpone final examination until all those from the same well have been received. As received they are put into bottles, labeled, given well and sample numbers, and put into a case for temporary filing. The object of the temporary files is to afford storage for samples from miscellaneous wells until the sets from the individual wells are complete. The cases are built in units with smooth ends 40 inches long, 32½ inches high, 24 inches deep, and are provided with glass doors to shut out the dust. Each contains 14 drawers in 2 rows of 7 each. Each drawer is 15½ by 20½ inches, inside measurement, and is 2½ inches deep. The guides are so placed that a space of three-fourths of an inch is left between each drawer to allow for the projecting bottles. The drawers are further subdivided by pasteboard partitions, similar to those used in packing eggs, into 108 compartments, each one of which will hold four of the smaller bottles or one of the large jars. The maximum capacity is 432 bottles to a drawer, or about 5,000 to a case. As but few of the larger jars are used, the actual capacity is very near the maximum.

Permanent storage of samples.—After examination, or when a set is complete, if desired the samples are filed in permanent storage cases of the same type as the temporary files. The compactness of the storage system will be appreciated when it is pointed out that over 200,000 samples can be stored in a 10 by 15 foot room. The samples are filed by wells, which are numbered consecutively as the reports are received, the numbers being entered on the record cards, which are filed alphabetically under States and counties.

RECORDS COLLECTED INDEPENDENTLY OF SAMPLES.

The most thoughtful drillers generally keep records of all wells drilled in new fields, but do not attempt to save samples, because of the labor involved in their handling and storage under ordinary conditions. Many of these records, which are often of much value in determining the geologic features of the region, have been, through the

courtesy of drillers and well owners, presented to the Survey. To facilitate the copying and filing of these records the following blank is used. The size of the original is 8 by 10½ inches.

Form used for obtaining well records.

WELL RECORD.

Well is located.....miles in a .....direction from.....post-office
in the.....¼ of.....¼ of sec....., twp....., range....., in the State of.....
Owner..... ... Contractor..... Driller..... .....
Well begun ....., 190..; completed....., 190..
Rig used: Cable, rotary, jet, or..... Total depth.....
Length of casing:.....ft. Diameter:....in. from.....ft. to.....ft.; ....in. from.....ft. to.....ft.
Water wells. {Completed well develops the following water-bearing strata: From.....ft. to.....ft., from.....ft. to.....ft., from.....ft. to..... Main supply from.....ft.
{Completed well pumps.....gals. per min. Flows.....gals. per min. Pressure.....
Oil and gas. {Pool or district..... Well No.....on.....farm
{Well yields ..... Yield first 24 hours..... Initial pressure.....
[Oil or gas.]
Records sent by..... Address.....

LOG OF WELL.

From—	To—	Character of material. (State whether hard or soft, and give color.)	Remarks. (Note especially depths and thickness of all water-bearing strata, height to which water from each layer rises, quality of the water from each, and yield in gallons per minute.)

CONFIDENTIAL RECORDS.

In many instances borings are put down at great expense for the simple purpose of testing for oil, gas, water, or mineral, or of determining the depth, character, and structure of coal, iron, or other mineral deposits. It can not be expected in such cases that the data obtained will be thrown open to others who have gone to no expense in the matter, but who would be only too glad to make use of the information for their own interest. It is almost universally recognized, however, that such information may be safely given to the United States Geological Survey, whose members are rigidly prohibited by law from having any personal or private interest in the lands or mineral wealth of the region under survey. Such informaton will, if desired, be regarded as strictly confidential, and a signed agreement by the Director to that effect will be given if requested. When confidential samples, records, or other information are received they are stamped "Confidential" and the material is securely cared for.

COOPERATION WITH STATE GEOLOGISTS.

In a number of States arrangements for cooperation have been made with State or local geologists. Two sorts of arrangements have been made. In Alabama, Iowa, Michigan, Minnesota, and West Virginia

the local geologists have furnished clippings, names of drillers, notices of wells, and other information or assistance. In Kentucky and Maryland, on the other hand, the State geologists act as the Survey's representatives, collecting the samples and records at the local offices and forwarding them to the Washington office.

PUBLICATIONS.

It is intended to issue annually a report giving the result of the year's work. The present paper is the first of the series and represents the material received during the first six months of the operation of the work. Being the first report, it will differ somewhat from those which are expected to follow, in that an account of the organization and methods are incorporated in addition to the well data. The general plan is to present each year a list of persons cooperating in furnishing samples or records, a summary of the wells reported and the results, and detailed records of wells. It is believed that the success of the work depends largely on making the material immediately available to drillers, well owners, and geologists rather than holding it for complete reports, which can generally be prepared only after many years of work, during which the information would be relatively inaccessible to those outside the Survey. Detailed reports, however, afford comprehensive views of the fields treated, which are not afforded by isolated records, and are to be prepared as opportunity offers.

WELL RECORDS.

By E. F. LINES.

The records which follow were reported in 1904. A summary of all the records received is given in the tables, and detailed reports of the more important wells are given on page 78.

The sources of information are the records in drillers' notebooks and on record forms, letters, drafts of well sections, and samples of borings.

SUMMARY OF WELL DRILLING REPORTED IN 1904.

Abbreviations used in table.

O, owner.
C, contractor.
D, driller.
M, miscellaneous sources of authority other than owner or driller.
L, Survey possesses a log.
S, Survey possesses samples.
– under "Height of water," distance of surface of water below the mouth of the well.
+ in same column, distance water will rise in an open pipe above the mouth of the well.
Under "Diameter" a series of figures indicates different diameters.

Summary of well drilling

ALABAMA.

No.	County.	Location.	T.	R.	S.	Owner.	Contractor.
1	Covington	Andalusia				Frank Sutter	
2	Madison	Hazelgreen, well No. 3				New York and Alabama Oil Co.	
3	Perry	Uniontown, 10 m. S. of				G. B. Johnston	John I. Hawk
4	Tallapoosa	Alexander City, well No. 2.	23	21	27	Alexander City	J. O. Heflin & Co.

ARKANSAS.

5	Arkansas	Dewitt	4 S.	3 W.	33	Mrs. Ella Johnson.	Gunter Bros.
6	do	do	5 S.	3 W.	4	Harry Meritt	do
7	do	Stuttgart				Edd Beity	do
8	do	Stuttgart, 15 m. SE. of	4	4	12	Fred Huffman	do
9	do	Stuttgart				G. H. Kline	do
10	Pike	Bowen				J. D. Hewitt	J. B. Dillon

CALIFORNIA.

11	Kern	Button Willow, 4 m. N. of.	28	23	25	C. B. Crawford	T. A. Pursell
12	do	Delano, 18 m. W. of	25	22	16	Frederick Cox	F. U. Pursell
a13	Monterey	Seaside				B. N. Baker	
a14	San Diego	Point Loma				Katherine Tingley	
15	San Francisco	San Francisco				J. L. Flood	
16	do	do				do	
17	Santa Cruz	Watsonville				City	
18	Tulare	Waukena				Waukena Water Co.	F. U. Pursell

a See detailed record at end of table.

reported in 1904.

ALABAMA.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute.		Year completed.	Kind of well.	Remarks.	No.
						Flow.	Pump.				
		Ft.	*In.*	*Ft.*		*Gals.*	*Gals.*				
.....	O.	420	....	367	.....	.....	.....	1904	Water .	.....	1
H. B. Conover..	M.	954	....	.....	.....	.....	.....	1904	Oil	No oil; yields some gas. (L. S.)	2
John I. Hawk ..	D.	875	4-3	855	— 40	.....	10	1904	Water .	Water stratum at 770 feet. (L. S.)	3
F. Osgood and J. Otis Heflin.	C.	300	10	260	−240	.....	55	1904	..do	Water stratum at 80 feet. (L. S.)	4

ARKANSAS.

Gunter Bros	C.	96	2	95	.....	.....	8	1904	Water .	Water stratum at 66 feet.	5
.....do	C.	101	2	98	.....	.....	.....	1904	..do	Abundance of water.	6
.....do	C.	95	....	.....	.....	.....	.....	1904	..do	.....	7
.....do	C.	103	2	98	.....	.....	8	1904	..do	.....	8
.....do	C.	100	....	100	.....	.....	.....	1904	..do	.....	9
J. B. Dillon.....	C.	170	....	.....	.....	.....	.....	1904	..do	Strong flow. (L. S.)	10

CALIFORNIA.

T. A. Pursell....	C.	365	10	311 323 346	.....	.....	.....	1904	Water .	Water at 80, 109, 131, 167, 176, 229, 242, and 357 feet. (L. S.)	11
F. U. Pursell....	C.	828	11-10-8-7	755	.....	1,077	.....	1904	..do	Water strata between 484 feet and bottom of well. Sulphur and other minerals.	12
.....	M.	617	....	610	.....	30	.....	1904	..do	Water-bearing beds at 270 and 540 feet. (L.)	13
.....	O.	400	6-5	.....	253	.....	24	1901	..do	Elevation of mouth of well 256 feet. A. T. (L.)	14
A. L. Lowe	M.	136	....	.....	.....	.....	.....	1904	..do	Abandoned. (L. S.)	15
.....do	M.	166	....	.....	.....	.....	.....	1904	..do	.....do	16
.....	....	150	7	.....	.....	.....	.....	.....	..do	Test well. Produces 400 gallons a minute.	17
F. U. Pursell ...	C.	868	10	470	.....	1,050	.....	1903	..do	.....	18

Summary of well drilling

COLORADO.

No.	County.	Location.	T.	R.	S.	Owner.	Contractor.
19	Denver	Denver	3S	68 W.	20	Dr. Albert A. Clough.	
20	Kiowa	Haswell				Missouri Pacific Rwy. Co.	
21	do	Stuart				do	
a22	Otero	Lajunta				Lajunta Oil and Gas Co.	

CONNECTICUT.

23	Fairfield	Noroton				Mrs. Anson Phelps Stokes.	Albert Lynch
24	do	do				Wee Burn Land Co.	do
25	do	Stamford				William Dashiell	do
26	Hartford	Farmington				C. F. Fienemann	E. D. Hammond
27	do	do				William S. Miles	do
28	do	do				H. T. Stenson	do
29	do	do				Gustav Wollenberg.	do
30	do	New Britain				Town of New Britain.	do
31	New Haven	Meriden				J. W. Britney	do

FLORIDA.

32	Franklin	Carrabelle				Carrabelle Oil and Development Co.	W. F. Hamilton.
33	Polk	Bartow				City of Bartow	do
34	St. John	St. Augustine				Hotel Ponce de Leon.	

a See detailed record at end of table.

reported in 1904—Continued.

COLORADO.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute.		Year completed.	Kind of well.	Remarks.	No.
						Flow.	Pump.				
		Ft.	*In.*	*Ft.*		*Gals.*	*Gals.*				
T. Carlton Keogle.	M.	260	4	230	− 38	.....	.....	1902	Water .	Yields soft water .	19
.....	M.	54	6¼	.....	− 45	.....	25	1903	..do	Abandoned on account of decrease in yield. (L.)	20
.....	M.	49	10¼	.....	− 30	.....	50	1902	..do	(L.).....	21
.....	M.	1,703	....	.....	.....	.....	.....	.....	Oil.....	(L. S.).....	22

CONNECTICUT.

Albert Lynch ..	C.	494	6–4¼	200	− 12	.....	4	1903	Water .	Water-bearing beds at 300 and 350 feet. Water hard.	23
.....do	C.	142	6	120	− 16	.....	20	1904	..do	Yields hard water.	24
George Northrop.	C.	69	6	60	.....	.....	12	1904	..do	.....	25
Delbert Howe ..	C.	40	6	35	.....	.....	.....	1904	..do	Pumps from 20 to 30 gallons per minute. (L.)	26
.....do	C.	50	6	50	.....	.....	25	1904	..do	.....	27
.....do	C.	37	6	.....	.....	.....	50	1904	..do	(L.).....	28
.....do	C.	118	6	108	− 40	.....	10	1904	..do	(L. S.)	29
.....do	C.	167	6	.....	.....	.....	2	1904	..do	Water at 75 and 155 feet. (L. S.)	30
.....do	C.	65	6	.....	.....	.....	10	1904	..do	Water at 40, 50, and 60 feet. (L.)	31

FLORIDA.

W. F. Hamilton.	M.	265	....	.....	.....	.....	.....	1904	Oil	Drilling suspended. (L. S.)	32
.....do	M.	725	....	.....	.....	.....	.....	1904	Water .	(L. S.)	33
.....	M.	1,278	....	.....	.....	.....	.....	.....	..do	"Flagler Well." Flow at 468, 1,110, and 1,200 feet, latter "milky with lime." Flow also at 1,225 feet. (L.)	34

Summary of well drilling

GEORGIA.

No.	County.	Location.	T.	R.	S.	Owner.	Contractor.
35	Berrien	Tifton				H. H. Tift	M. H. Junard
36	Burke	Midville				Allen W. Jones	W. H. Brown
37	Lee	Smithville				City	
38	Walker	Chickamauga Park				U. S. Government	
39	do	do				do	

IDAHO.

40	Fremont	Dubois				San Pedro, Los Angeles and Salt Lake Rwy. Co.	L. J. Craig

ILLINOIS.

41	Adams	Payson				Jos. Scarborough	A. J. Clark
a42	Boone	Belvidere				Chicago and Northwestern Rwy.	L. Wilson Well Co.
43	Clark	Dave Lee farm				Hoblitzell & Co.	
44	do	John Newlin farm				do	
45	do	Phillips farm				do	
a46	Dupage	Naperville				Naperville water Works.	L. Wilson Well Co.
a47	Henry	Kewanee	15 N.		32	Kewanee Boiler Co.	J. P. Miller Artesian Well Co.
48	Lake	Libertyville					W. J. Miller's Sons.
49	do	Russell, 5 m. SW. of	46	11	18	Wilson King	W. M. Bolles
50	do	Russell	46	11	22	Estate of George Shea.	do
51	do	Waukegan	45	11	1	W. H. Finch	do
a52	Lasalle	Streator				Streator Bottle and Glass Works.	L. Wilson Well Co.

a See detailed record at end of table.

reported in 1904—Continued.

GEORGIA.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute. Flow.	Yield per minute. Pump.	Year completed.	Kind of well.	Remarks.	No.
		Ft.	*In.*	*Ft.*		*Gals.*	*Gals.*				
.....	M.	368	8	330	−125	.....	150	1901	Water.	Hard; some sulphur. Temperature 73°.	35
.....	O.	750	5	700	+ 47	75	.....	1901	..do	Hard; iron and sulphur. Water-bearing beds at 200, 300, and 450 feet. Temperature 68°.	36
O. L. Herrington	M.	900	4-3	.....	+ 18 to + 24	35	.....	1890	..do	Soft. Water-bearing beds at 350 to 400 feet. Temperature 73°.	37
.....	M.	306	6	305	− 25	.....	106	1904	..do	Hard. Water at 110 and 290 feet. In dry season water falls to −100 feet.	38
.....	M.	306	10	305	− 25	.....	183	1904	..do	This well is 10 feet from one above; pumping one lowers the other correspondingly.	39

IDAHO.

.....	C.	615	....	.....	.....	.....	50	1903	Water.	Water-bearing beds began at 375 feet.	40

ILLINOIS.

.....	C.	1,542	5¼-4¼	167	−150	.....	13	1904	Water.	Fresh water from 167 to 1,000 feet, brine at 800 and 1,400 feet.	41
H. W. Hambrecht; H. Hemhoff.	D.	1,231	10-8-6¼	.....	−20	.....	180	1903	..do	Water-bearing beds at 574, 834, 1,070, and 1,231 feet. (L.)	a42
J. N. Schell.....	O.	360	....	.....	.....	.....	.....	1904	Oil.....	Oil at 360 feet.....	43
.....do	O.	354	....	.....	.....	.....	.....	1904	..do	Oil at 354 feet.....	44
.....do	O.	385	....	.....	.....	.....	.....	1904	..do	Oil at 385 feet.....	45
H. W. Hambrecht; H. Hemhoff.	D.	1,425	12-10-8-6¼	.....	.....	.....	140	1904	Water.	Water-bearing beds at 792 and 1,425 feet. (L.)	46
L. Nichols; Wm. Trentlage.	D.	1,073	12-10¼-8¼-6	954 to 1,073	−350	.....	80	1904	..do	Coal, 3 feet, at 187 feet; water at 415 feet. (L. S.)	47
.....	C.	179	....	.....	.....	.....	.....	.....	..do	Water-bearing beds at 11 and 45 feet.	48
W. M. Bolles....	C.	255	4¼	255	.....	.....	25	1904	..do	Water stratum at 150 feet.	49
.....do	C.	175	4	175	−12	.....	20	1904	..do	Soft; sulphurous. (L. S.)	50
.....do	C.	205	4	205	−59	.....	18	1904	..do	(L. S.)	51
H. W. Hambrecht; H. Hemhoff.	D.	1,115	8-6	.....	.....	.....	130	1902	..do	Water-bearing beds at 596, 706, 834, 1,056, and 1,096 feet. (L.)	a52

Summary of well drilling

ILLINOIS—Continued.

No.	County.	Location.	T.	R.	S.	Owner.	Contractor.
53	Lasalle	Streator				Streator Clay Manufacturing Co.	L. Wilson Well Co.
54	McHenry	Hebron				Village of Hebron	W. J. Miller's Sons.
55	.....do	Richmond	46	8	9	L. B. Covell	.....do
56	.....do	.....do	46	8	9	F. McConnell	.....do
57	Sangamon	Springfield, 4½ m. N. of.	16 N.	5 W.	10	City	
58	.....do	.....do		.....do		.....do	
59	.....do	.....do		.....do		.....do	
60	Will	Crete				C. and E. I. Rwy. Co.	

INDIANA.

61	Dekalb	Garrett				Baltimore and Ohio Rwy. Co.	Harmon Water Supply Co.
a62	Delaware	Albany, Whitehair farm, well No. 1.			24	Brewster Oil Co.	St. Marys Drilling Co.
63	.....do	Muncie, 4 m. S. of				Eureka Oil Co	
a64	Jay	Redkey, Hoppis heirs farm, well No. 5.	12	E.	24	Dunkirk and Redkey Oil-Gas Co.	O. O. McCormic.

INDIAN TERRITORY.

65	Cherokee Nation.	Bartlesville					
66	Osage Nation	Pawhuska					

IOWA.

67	Bremer	Frederika				Pioneer Prospecting Oil Co.	L. Wilson Well Co.
c68	Cedar	Tipton				City	
a69	Cherokee	Cherokee	92	40	28	Cherokee State Hospital.	
a70	Des Moines	Burlington				Iowa Soap Co	R. J. Johnston
a71	Scott	Davenport				Independent Malting Co.	L. Wilson Well Co.
72	Woodbury	Sioux City, 3 m. NW, of.				John Bushar	

a *See detailed record* at end of table.
c *See detailed record* in report of Iowa Geological Survey, Vol. III, p. 191.

reported in 1904—Continued.

ILLINOIS—Continued.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute. Flow.	Yield per minute. Pump.	Year completed.	Kind of well.	Remarks.	No.
		Ft.	*In.*	*Ft.*		*Gals.*	*Gals.*				
H. W. Hambrecht; H. Hemhoff.	D.	773	9-7	.....	.....	.....	94	1903	Water.	Coal at 223 feet; fire clay at 236 feet. This clay used for making tile. (L.)	53
.....	C.	269	....	258	−61	.....	80	.....	..do	Water bearing stratum 60 to 148 feet. Water muddy. (L.)	54
L. C. and W. E. Trow.	D.	84	5	84	−38	.....	12	1904	..do	(L. S.)	55
.....do	D.	92	5	92	.....	.....	12	1904	..do	(L. S.)	56
.....	M.	46	10	33	−11	.....	350	1904	..do	(L. S.)	57
.....	M.	4[illegible]	....	30	.....	.....	.....	1904	..do	The 3 wells are 100 feet apart. (L. S.)	58
.....	M.	49	....	35	.....	.....	.....	1904	..do	(L. S.)	59
.....	M.	275	8	275	−25	.....	.....	1904	..do	Hard water at 200 feet.	60

INDIANA.

A. D. Harmon..	C.	266	10	219 to 266	.....	.....	190	1904	Water.	(L. S.).....	61
Wm. Walters; Wm. Jamison.	D.	1,262	8-6½	.....	.....	.....	.....	1904	Oil	Small amount of oil. (L. S.)	62
H. J. Hughes...	M.	1,243	....	.....	.....	.....	.....	1904	..do	.....	63
Harry Albert; Geo. Albert.	M.	1,385	8-6½ 2	1,380	.....	.....	b5	1904	..do	Gas at 960 feet. (L. S.)	64

INDIAN TERRITORY.

.....	M.	1,700	....	.....	.....	.....	.....	.....	.....	Oil at 1,286 feet. (L.)	65
.....	M.	2,000	....	.....	.....	.....	.....	.....	.....	Water at 1,145 feet. Gas pressure at 2,000 feet prevented further drilling. (L.)	66

IOWA.

H. W. Hambrecht, H. Hemhoff.	D.	1,025	8-6½	.....	−4	.....	148	1902	Water.	Water-bearing beds at 367, 717, and 883 feet. Well drilled for oil. (L.)	67
W. N. Treichler.	M.	2,699	....	.....	.....	50	.....	.....	..do	(L. S.)	68
O. G. Wilson....	M.	1,120	12-9	1,120	−206	.....	7	1902	..do	Water-bearing beds at 225, 375, 405, 475, and 535 feet. Temperature 60°. Water hard. (L.)	69
R. J. Johnston..	C.	507	5½	435	.....	45	.....	1904	..do	(L. S.)	70
H. W. Hambrecht. H. Hemhoff.....	D.	1,300	10-8	1,050	.....	310	.....	1904	..do	Water began to flow at depth of 996 feet. (L.)	71
Jace Carter.....	M.	98	....	90	−50	.....	.....	1904	..do	(L. S.)	72

[b] Barrels a day.

Summary of well drilling

KANSAS.

No.	County.	Location.	T.	R.	S.	Owner.	Contractor.
73	Allen	Laharpe					
74	Barton	Hoisington				Missouri Pacific Rwy. Co.	
75	Butler	Rosalia					
76	Chautauqua	Hale. J. W. Darbro farm, well No. 1.	32	12	13	Darbro Oil Co	C. F. Noble
77	do	Hewins	35	9	12	Sterling Oil and Gas Co.	Alexander Bros. & Stauffer.
a78	Greeley	Horace				Missouri Pacific Rwy. Co.	
79	Greenwood	Eureka					
a80	do	Neal. Robb farm, well No. 3.	25	12		Raff & Gammon	Kennedy & Son.
81	do	Neal					
82	Montgomery	Independence. (Heckart No. 1).	34	15	1	Yoke & Brown	Patton & Wolford.
a83	do	Independence. (Logan No. 1).	33	15	27	do	do
a84	Neosho	Chanute. S. Smith farm, well No. 22.	27	18	10	I. N. Knapp	
85	do	Rollin (near)	28	19 E.	9	Shaw farmers	
86	Pottawatomie	Onaga	7	11	11		Bennett & Robbins.
87	Reno	Haven, 6 m. S. of	26	4	6	J. F. Eabling	E. A. Roberson.
88	Rush	Bison				Missouri Pacific Rwy. Co.	
89	do	McCracken				do	
90	Sedgwick	Andale	26	3 W.	8	M. Lill	E. A. Roberson.
91	Woodson	Toronto					

KENTUCKY.

92	Warren	Bowling Green					
93	do	Bowling Green, 6 m. NW. of.				Warren Petroleum Co.	

a See detailed record at end of table.

reported in 1904—Continued.

KANSAS.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute. Flow.	Yield per minute. Pump.	Year completed.	Kind of well.	Remarks.	No.
		Ft.	*In.*	*Ft.*		*Gals.*	*Gals.*				
.....	M.	1,050	.....	.....	.....	.....	.....	.....	.....	.....	73
.....	M.	200	6¼–5½–5¼	184	.....	.....	.....	1900	Water.	(L.)	74
.....	M.	2,062	.....	.....	.....	.....	.....	.....	Oil.....	Salt water at 733 and 1,350 feet. Water at 1,710 feet. Drilling suspended.	75
W. B. Frost; Lee McClung.	M.	1,106	10–8¼–6¼	.....	.....	.....	.....	1904	..do	Salt water at 365 and 800 feet. Very little oil.	76
.....	M.	1,479	8¼–6¼–4¼	.....	.....	.....	.....	.....	..do	Salt water at 510, 775, and 1,060 feet. Pay sand 1446–1474. (L.)	77
.....	M.	1,370	10	1,325	−830	.....	30	1904	Water.	Water at 825 and 1,325 feet. Well abandoned. (L.)	78
.....	M.	1,255	.....	.....	.....	.....	.....	.....	.....	Brine at 499 feet.	79
.....	O.	940	10–8¼	.....	.....	.....	.....	1904	Oil.....	Water-stratum at 882 feet. (L.)	80
.....	M.	875	.....	.....	.....	.....	.....	.....	.....	.....	81
C. A. Williams; D. Hurst.	O.	1,041	8¼–3	.....	.....	.....	.....	1904	Gas....	Yield 11,000,000 feet first 24 hours. (L.)	82
C. A. Williams..	O.	1,160	8¼–6¼	.....	.....	.....	.....	1904	..do	Water-bearing beds at 275, 640, and 895 feet. Yield 18,000,000 feet first 24 hours. (L.)	83
Roy Bair.....	M.	752	5	.....	.....	.....	*b*5	1904	Oil	Water at 30, 128, 521 feet. Brine at 385 feet. Oil at 720, 724, 728 feet. (L. S.)	84
.....	M.	652	.....	640	.....	.....	*b*5	1904	..do	The oil grades 32°. (L.)	85
Bennett & Robbins.	C.	602	3–2	540	.....	5	.....	1904	.....	Gas and flowing water 533 to 559 feet. (L. S.)	86
E. A. Roberson..	C.	39	12–5	39	.....	.....	52	1904	Water.	(L. S.)	87
.....	M.	291	8¼	282	−55	.....	90	.....	..do	(L.)	88
.....	M.	558	8¼–6¼	278	.....	.....	20	1901	..do	Water at 278 and 382 feet. Salty. (L.)	89
E. A. Roberson..	C.	52	10–6	50	.....	.....	30	1904	..do	Water at 30 feet. (L.)	90
.....	M.	1,140	.....	.....	.....	.....	.....	.....	.....	Oil at bottom.....	91

KENTUCKY.

.....	M.	1,300	.....	.....	.....	.....	.....	.....	Oil	(S.)	92
.....	M.	600	.....	.....	.....	.....	.....	.....	..do	.....	93

b Barrels a day.

Summary of well drilling

LOUISIANA.

No.	County.	Location.	T.	R.	S.	Owner.	Contractor.
94	Calcasieu	Edgerley	10	11	22	D. C. Brown	V. Wainright
95	do	Calcasieu				Louisiana Oil Co.	Oscar Shanks
96	Rapides	Pineville				State of Louisiana	do
97	Vermilion	Gueydan, 5 m. SW. of	12	2	15	A. B. Wilkinson	V. Wainright

MAINE.

98	Androscoggin	Lisbon Falls, 16 m. W. of.				Worombo Woolen Mills.	Andrew S. Merrill.
99	Oxford	Rumford Falls				Rumford Falls Light and Water Co.	Chas. Ray
100	Sagadahoc	Small Point				Geo. O. Curtis	Smith & Thayer Co.

MASSACHUSETTS.

101	Hampden	East Longmeadow				Frank Bane	F. A. Champlin
102	do	Springfield				Andrew Kewic	do
103	do	Springfield, 4 m. N. of				E. Perkins	do
104	do	do				Thomas Webb	do
105	Worcester	North Grafton				A. W. Baker	G. W. Patterson
106	do	Shrewsbury				J. E. Dufresne	do
107	do	Worcester				M. H. Cowden	do
108	do	do				Mary E. Stevens	do

MICHIGAN.

109	Berrien	Benton Harbor				Saltzman Mineral Bath Co.	Cartwright & Sherry.
110	Hillsdale	Prattville				Henry Fickley	F. Howard
111	Iosco	East Tawas				Michigan Pipe Co.	
112	Kent	Grand Rapids (Greenwood Cemetery).				City of Grand Rapids.	O. L. Taylor & Son.
113	Luce	Newberry				Superior Chemical Co.	Jas. Kinney, jr.
114	Mason	Fountain				Martin H. Foster	
115	Oakland	Holly				City of Holly	
116	Ontonagon		48	39	7	Leo M. Geismar	
117	Wexford	Bagnall	23	12 W.	4		Lewis Maule

reported in 1904—Continued.

LOUISIANA.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute. Flow.	Yield per minute. Pump.	Year completed.	Kind of well.	Remarks	No.
		Ft.	*In.*	*Ft.*		*Gals.*	*Gals.*				
V. Wainright	C.	535	10	390	0	225	1,800	1904	Water.	(L. S.)	94
Oscar Shanks	C.	2,200	....	1,005	.....	.....	250	1901	.....	Well yields very warm, salty water. (L. S.)	95
.....do	C.	428	....	.....	.....	.....	.....	1904	.....	(L. S.)	96
V. Wainright	O.	280	12	150	5	.....	.....	1904	Water.	Temperature 60°. Water hard.	97

MAINE.

C. E. Shute	D.	215	6¼	63	.....	.....	35	1904	Water.	Hard water at 23 and 75 feet. Temperature 54°. (L. S.)	98
John White; Walter Follett.	M.	60	2¼	20	.....	.....	25	1904	..do	(L. S.)	99
J. J. McDonald	D.	100	6	79	.....	.....	2	1904	..do	.....	100

MASSACHUSETTS.

James Egan	D.	75	6	75	.....	.....	2	1904	Water.	.....	101
.....do	D.	275	6-4¼	250	.....	.....	20	1904	..do	(L. S.)	102
.....do	D.	60	6	50	.....	.....	1	1904	..do	.....	103
.....do	D.	59	6	50	.....	.....	2¼	1904	..do	.....	104
Geo. W. Carman	D.	27¼	6	25	.....	.....	30	1904	..do	Soft. (L.)	105
.....do	D.	80	6	58	.....	.....	5	1904	..do	Water at 35 feet. Soft. (L. S.)	106
.....do	D.	48	6	47	.....	.....	5	1904	..do	Water at 28 feet. Soft. (L.)	107
.....do	D.	41	6	.....	.....	.....	.....	1904	..do	Water at 30 and 35 feet. Pumps 6 gallons an hour. (L.)	108

MICHIGAN.

Cartwright & Sherry.	M.	750	8	.....	—30	.....	.....	1904	Water.	Yields abundance of strong mineral water. (L. S.)	109
F. Howard	C.	106	3	105	—44	.....	.....	1904	..do	Iron and sulphur. (L. S.)	110
.....	O.	271	5	.....	.....	.....	.....	1900	Salt.	(L.)	111
Fred Taylor	D.	364	6-5	264	.....	.....	100	1904	Water.	(L. S.)	112
F. F. Copeland	C.	100	....	.....	.....	20	.....	1904	..do	One of a series of 9 wells. All about same depth and yield. Temperature 42°. (L. S.)	113
Fred Sherer	O.	97	2	97	.....	.....	.....	1904	..do	Water at 32 feet. Hard.	114
.....	M.	184	....	.....	.....	.....	.....	1904	..do	.....	115
J. A. Colwell	D.	95	....	.....	.....	.....	.....	1904	..do	No water. (L. S.)	116
Lewis Maule	C.	105	2	.....	—97	.....	.....	1904	..do	(L.)	117

Summary of well drilling

MINNESOTA.

No.	County.	Location.	T.	R.	S.	Owner.	Contractor.
118	Freeborn	Albert Lea	102	21	5	John Tennis	J. E. Sharp
119	Kandiyohi	Atwater				City of Atwater	J. F. McCarthy
120	Polk	Fertile				Northern Pacific Rwy. Co.	do
121	Steele	Blooming Prairie				H. Shaw	

MISSISSIPPI.

a122	Hancock	Bay St. Louis				Peerless Oyster Co.	John A. Sutter
123	do	Waveland				Chas. L. Hopkins	do
124	Harrison	Pass Christian, 3 m. E. of.				Misses Miltenberger.	do
125	do	Wortham				Gulf and Ship Island R. R. Co.	do
a126	Jackson	Mosspoint				L. N. Dantzler Lumber Co.	do

MISSOURI.

a127	Randolph	Moberly					A. P. Phillips
128	St. Louis City	St. Louis	46 N.	6 E.		C. D. Garnett	H. W. Steinsick
a129	do	do				Welle Boultler Baking Co.	C. S. Wise

MONTANA.

130	Flathead	Kintla Lake				Butte Oil Co	
131	Teton	Chief Mountain Lake					

a See detailed record at end of table.

reported in 1904—Continued.

MINNESOTA.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute. Flow.	Yield per minute. Pump.	Year completed.	Kind of well.	Remarks.	No.
		Ft.	*In.*	*Ft.*		*Gals.*	*Gals.*				
J. E. Sharp.....	C.	127	2	115	−104	.....	.....	1904	Water.	Hard water in abundance. (L. S.)	118
E. Espy.....	D.	453	8-6	414	.....	.....	100	1904	..do....	Water strata at 45, 100, and 310 feet. (L. S.)....	119
E. Christofferson.	D.	296	8-6	280	.....	−25	100	1904	..do....	(L. S.).....	120
Jim O'Neil.....	D.	100	2	.....	+ 2	.....	.....	1904	..do....	Water soft.....	121

MISSISSIPPI.

John L. Ford...	D.	897	3	818	.....	225	.....	1904	Water.	Water at 690 feet, flowed 50 gallons a minute. (L. S.)	122
.....do.....	D.	775	3	700	.....	165	.....	1904	..do....	Water at 350 feet. (L. S.)	123
John Ford.....	C.	747	3	727	.....	225	.....	1904	..do....	Water stratum 628 to 747 feet. (L. S.)	124
Archie Dickson.	C.	590	3	500	.....	100	.....	1904	..do....	Water began to flow at 110 feet. (L. S.)	125
John L. Ford...	D.	790	3	770	.....	135	.....	1904	..do....	(L. S.).....	126

MISSOURI.

A. P. Phillips...	C.	2,100	....	.....	.....	.....	.....	1902	Oil.....	Water at 632 feet. Brine at 870 and 1,215 feet. Water rose to −70 feet. (L.)	127
H. W. Steinsiek.	C.	518	5¼–4¼	500	.....	.....	15	1904	Water.	(L. S.).....	128
Ed. Meloy..... A. W. Dickinson.	D.	650	8-¼	.....	.....	.....	.....	1904	Oil.....	Water at 140 and 185 feet. A showing of oil at 280, 305, 510, and 600 to 650 feet. Dry hole. (L. S.)	129

MONTANA.

.....	M.	1,405	....	.....	.....	.....	.....	1904	Oil.....	.....	130
.....	M.	1,020	....	.....	.....	.....	[b] 30	.....	..do....	Lubricating oil well. Just north of United States boundary line.	131

[b] Barrels a day.

Summary of well drilling

NEBRASKA.

No.	County.	Location.	T.	R.	S.	Owner.	Contractor.
132	Buffalo	Shelton				Village of Shelton.	
133	Dodge	Scribner				Chicago and Northwestern Rwy. Co.	
134	Saunders	Cedar Bluffs				City	
135	Webster	Rosemont					

NEW HAMPSHIRE.

136	Belknap	New Hampton				Hanna M. Walker.	G. W. Patterson.
137	Merrimack	New London				Chas. G. Davis	Artesian well and Supply Co.
138	do	Potter place				Shepard & Gould.	do
139	do	New London				Chas. Shepard	do
140	Sullivan	Burkehaven				Tuxbury Bros	do

NEW JERSEY.

a141	Atlantic	Pleasantville				Water Department, Atlantic City.	Thos. B. Harper.
142	do	do				do	do
143	Cape May	Woodbine				Woodbine Land Co.	Ridpath & Potter.
144	Hudson	Jersey City				Jno. Mehl & Co	P. H. and J. Conlan.
145	Middlesex	Keasbey				Wm. Dunham	W. R. Osborne
146	do	do				Mrs. Jas. A. Noye	do
147	do	Metuchen				Mr. Avery	do
148	do	do				Mr. Berkold	do
149	do	Perth Amboy				Barber Asphalt and Paving Co.	do
150	do	Perth Amboy, 3 m. S. of				Chas. Bloomfield.	do
151	do	Perth Amboy				W. J. Daniels	do
152	do	do				Raritan Coffee Works.	do
153	do	do				Standard Underground Cable Co.	Stotthoff Bros.
154	do	Amboy				George Seamans	W. R. Osborne
155	do	do				R. N. and H. Valentine.	do

a See detailed record at end of table.

reported in 1904—Continued.

NEBRASKA.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute.		Year completed.	Kind of well.	Remarks.	No.
						Flow.	Pump.				
		Ft.	*In.*	*Ft.*		*Gals.*	*Gals.*				
.....	M.	52½	....	45½	.....	.....	.....	.....	Water .	One of a series of wells. (L.)	132
L. C. Dewitt....	D.	78	6	.....	−12	.....	.....	1904	..do	Two wells pump together 10,000 gallons per hour. (L.)	133
W. A. Morris ...	M.	124	8	.....	.....	.....	147	1904	..do	Water-bearing bed at 57½ feet. Water hard.	134
Class Rose.....	M.	409	....	.....	.....	.....	.....	.....	.....	Iron ore at 375 feet. Oil at 379 feet. (L.)	135

NEW HAMPSHIRE.

Geo. W. Carman.	D.	75	6	.....	.....	.....	.....	1904	Water .	No water. Abandoned. (L. S.)	136
N. F. Harris....	....	50	8	.....	−25	.....	4	1904	..do	Water soft. Temperature, 47°.	137
.....do	D.	38	6	38	−10	.....	30	.....	..do	Water soft.....	138
.....do	D.	218	8	195	−10	.....	4	1904	..do	Water soft. Temperature, 50°. (L. S.)	139
.....do	D.	70	8	70	−10	.....	5	1904	..do	Water soft. Temperature, 47°.	140

NEW JERSEY.

.....	M.	320	4½	.....	.....	....	. ....	1903	Water .	Test well. Water at 35, 80, and 138 feet. Not pumped. (L. S.)	141
.....	M.	190	6	136	.....	50	. ....	1904	..do	Well No. 2. Water stratum 180 to 190 feet. (L. S.)	142
.....	C.	152½	6–4	125	.....	....	60	1904	..do	Water at 6, 106, and 140 feet. (L.)	143
.....	M.	1,020	8	.....	−110	....	125	1898	..do	Water at 780 and 1,000 feet. Soft. Temperature 54°.	144
.....	C.	85	4	85	.....	....	. ....	1904	..do	(L.).....	145
.....	C.	114	4	90	.....	.....	.....	1904	..do	(L.).....	146
.....	M	32	4	32	.....	.....	.....	1904	..do	(L.).....	147
.....	C.	56	4	56	.....	.....	. .	1904	..do	Water in abundance. (L.)	148
.....	C.	50	6	45	.....	.....	{ 25 / 50 }	1904	..do	Two wells. (L.)...	149
.....	C.	63	....	63	.....	.....	. .	1904	..do	(L.).....	150
.....	C.	52	....	45	.....	.....	. .	1904	..do	(L.).....	151
.....	C.	150	8–4	.....	.....	.....	140	1904	..do	(L.).....	152
.....	C.	153	6	135	−23	70	. .	.	..do	Well No. 5. Water stratum at 90 feet. (L.)	153
.....	C.	75	4	60	.....	.....	. .	.	..do	(L.).....	154
.....	C.	50	4	50	.....	.....	. .	1904	..do	.....	155

Summary of well drilling

NEW JERSEY—Continued.

No.	County.	Location.	T.	R.	S.	Owner.	Contractor.
156	Middlesex	Woodbridge				T. F. Dunnigan	W. R. Osborne
a157	Monmouth	Atlantic Highlands				Borough of Atlantic Highlands.	Ambrose Matthews.
158	Union	Cranford				Henry Deyan	F. T. Cladek
159	do	Elizabeth on Rahway				John Bedon	do
160	do	Westfield				Bertram E. Ball	do
161	do	do				Charles Peifer	do
162	Warren	Martens Creek				Seitz Brewing Co.	Stotthoff Bros.

NEW MEXICO.

163	San Miquel	Chapelle				A. T. and S. F. R. R.	C. H. McVay

NEW YORK.

164	Allegany	Ceres McDonald farm, well No. 1.				J. T. Barnes	E. C. Strait
165	Herkimer	Newport				Condensed Milk Co.	Alex. T. Gibson.
166	Madison	Georgetown station				Mutual Milk and Cream Co.	
167	Monroe	North Rush				State Industrial School.	E. A. Jenkins.
168	Nassau[b]	Freeport				City of Freeport	
b69	do	Laurelton				E. C. Henderson	E. K. Hutchinson & Son.
170	do	do				do	do
171	do	Oyster Bay (near Mill Neck).				W. R. Peters	
172	Onondaga	Bromley, 8 m. S. of				School district No. 11.	
173	do	Tully				Ovid S. Trail	
a174	do	do				Solway Process Co.	
175	Richmond	Sea Breeze					W. R. Osborne
176	Suffolk	Brentwood				Wm. H. Moffit	
177	do	Cold Spring Harbor				W. Jennings	Hudson Engineering Co.
178	do	Pinelawn				A. B. Sobother	
179	Westchester	Harrison, 3 m. N. of				John W. Sterling	George R. Bliss.
180	do	do				do	do

[a] See detailed record at end of table.
[b] For additional records of wells on Long Island see Professional Paper No. 44.

reported in 1904—Continued.

NEW JERSEY—Continued.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute. Flow.	Yield per minute. Pump.	Year completed.	Kind of well.	Remarks.	No.
		Ft.	*In.*	*Ft.*		*Gals.*	*Gals.*				
.....	C.	32	....	32	.....	.....	.....	.....	Water .	.....	156
Elias Brower ...	M.	450	4¼	412	.....	20	125	1904	..do	(L. S.)	157
F. T. Cladek....	C.	121	6	.....	−17	.....	14	1904	..do	.....	158
.....do	C.	67	4¼	60	−18	.....	21	1904	..do	(L. S.)	159
.....do	C.	119	4¼	108	−29	.....	20	1904	..do	(L. S.)	160
.....do	C.	96	5	90	.....	.....	18	1904	..do	(L. S.)	161
H. S. Barnett....	C.	140	6	120	−70	.....	20	1904	..do	(L.)	162

NEW MEXICO.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute. Flow.	Yield per minute. Pump.	Year completed.	Kind of well.	Remarks.	No.
J. Scully..... J. Polley..... W. Canfield	M.	960	13–8	930	−310	.....	25	1903	Water .	Water-bearing beds at 120 and 380 feet. (L.)	163

NEW YORK.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute. Flow.	Yield per minute. Pump.	Year completed.	Kind of well.	Remarks.	No.
E. C. Strait..... D. Brumbaugh .	C.	1802	8-6½	.....	.....	.....	.....	1904	Gas	Oil at 710 and 1,060 feet; gas at 500 and 1,110 feet; yield, 15,000 cubic feet a day. (L. S.)	164
.....	C.	96	....	90	−10	.....	.....	1904	Water .	.....	165
Lawson B. Cuyle	M.	75	....	60	.....	.....	.....	.....	..do	.....	166
E. A. Jenkins...	C.	115	5½	.....	− 5	.....	50	1904	..do	.....	167
F. W. Miller....	M.	.....	10	.....	.....	.....	600	1904	..do	Series of wells	168
.....	M.	58	8	.....	43	.....	.....	.....	..do	Well No. 1. (L. S.).	169
.....	M.	126	6	.....	−42	.....	.....	.....	..do	Well No. 2; 30 feet from No. 1. (L. S.)	170
C. H. Davis.....	D.	72	....	40	.....	.....	.....	1904	..do	Abundance of water. (S.)	171
L. C. Barber....	D.	112	5	.....	.....	.....	7	1904	..do	.....	172
.....do	D.	104	6	.....	.....	.....	7	1904	..do	.....	173
.....	O.	973 to 1,526	.....	.....	.....	.....	.....	1899 to 1900	Brine..	21 wells. Salt beds at depths between 935 and 1,520 feet. (L.)	174
.....	C.	100	....	.....	− 3	.....	25	1904	Water .	Irony. (L.)	175
J. Elliott.....	D.	37	....	.....	−27	.....	.....	1904	..do	.....	176
Frank Wankel..	D.	400	8	280	.....	.....	75	1904	..do	Water at 276 and 303 feet. (L. S.)	177
J. Elliott.....	D.	50	....	.....	−40	.....	.....	1904	..do	.....	178
George R. Bliss.	C.	255	6	250	−29	.....	18	1904	..do	Well No. 1. Water at 50, 85, 205, 230, and 245 feet. (L. S.)	179
.....do	C.	212	6	212	− 4	.....	5	1904	..do	Well No. 2. Water at 160 and 200 feet. (L.)	180

Summary of well drilling

NORTH CAROLINA.

No.	County.	Location.	T.	R.	S.	Owner.	Contractor.
181	Lenoir	Kinston				City of Kinston	

OHIO.

182	Cuyahoga	Cleveland				Hamby Realty Co.	Dibble & Ernest.
183	do	Gates Mill				S. P. Baldwin	do
184	do	do				E. A. Foot	do
185	do	do				Mr. Ginrich	do
186	do	do				F. T. Showls	do
187	do	South Euclid				Mr. Cousins	do
188	do	do				H. Faust	do
189	do	do				Mrs. K. Martins	do
190	do	do				F. McFarland	do
191	do	South Euclid, 3 m. NW. of.				Northern Ohio Squab Co.	do
192	do	South Euclid				R. E. Smith	do
193	Geauga	Auburn				Corwin Hall	do
194	do	Chardon				F. Curtis	do
195	do	do				H. Hadlon	do
196	do	do				Kiser & Winchel	do
197	do	do				William Martins	do
198	do	do				F. Stafford	do
199	do	Ford				W. B. Cleveland	do
200	do	do				do	do
[a]201	Hancock	Findlay				C. L. Casterline	G. L. Cusac
202	do	Portage Twp. Smith farm. Well No. 8.			31	Bradford Oil Co	
203	Licking	Utica, 7 m. W. of				Central Ohio Natural Gas and Fuel Co.	Pearsall & Co.
204	Mahoning	Youngstown, 2 m. W. of.				W. H. Lewis	
205	do	Youngstown, 3 m. E. of.				do	
206	do	do				do	
207	do	Youngstown, 2 m. N. of.				do	
208	do	Youngstown, 6 m. N. of.				do	
209	Marion	Martel					
210	Montgomery	Dayton				Dayton State Hospital.	Jas. Kinney, jr.

[a] See detailed record at end of table.

reported in 1904—Continued.

NORTH CAROLINA.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute. Flow.	Yield per minute. Pump.	Year completed.	Kind of well.	Remarks.	No.
		Ft.	*In.*	*Ft.*		*Gals.*	*Gals.*				
W. C. Martin ...	M.	310	....	.....	.....	.....	.....	1904	Water .	(L. S.)	181

OHIO.

.....	C.	30 80 85	...	.....	.....	.....	.....	1904	Water .	Three wells. Small yield.	182
E. Prince	....	148	8	.....	.....	.....	3	1904	..do	(L.)	183
.....	C.	59	5½	59	.....	.....	4	1904	..do	(L.)	184
.....	C.	169	4	169	− 9	.....	8	1904	..do	Well in old river channel.	185
.....	C.	186	....	.....	−40	.....	6	1904	..do	(L.)	186
E. Prince	C.	87	5½	87	.....	.....	2	1904	..do	(L.)	187
E. D. Ernest.....	C.	123	5½	110	.....	.....	8	1904	..do	.....	188
E. Prince	C.	50	5½	48	.....	.....	3	1904	..do	.....	189
.....do	C.	22	5½	.....	.....	.....	2	1904	..do	.....	190
.....do	C.	67	5½	.....	.....	.....	2	1904	..do	.....	191
E. D. Ernest.....	C.	121	5½	120	−15	.....	24	1904	..do	(L. S.)	192
.....	C.	40	5½	.....	.....	.....	2	1904	..do	.....	193
.....	C.	39	5½	.....	.....	.....	2	1904	..do	.....	194
.....	C.	186	5½ 4½	.....	.....	.....	.....	1903	..do	All quicksand below 40 feet.	195
.....	C.	75	4½	.....	.....	.....	6	1904	..do	Soft.....	196
George Waite...	C.	64	4½	64	.....	.....	5	1904	..do	.....	197
.....	C.	38	5½	.....	.....	.....	2	1904	..do	.....	198
.....	C.	260	7 5½ 4½	.....	.....	.....	.....	1903	..do	Water-bearing beds at 85 and 260 feet.	199
.....	C.	103	5½	100	.....	.....	8	1903	..do	.....	200
O.P.Fike; C.Hill	M.	1,158	6½	.....	.....	.....	.....	1904	Gas....	Water at 50 and 60 feet; brine at 540 feet; small amount of gas; well abandoned. (L. S.)	201
O. P. Fike	M.	1,414	....	.....	.....	.....	.....	1904	Oil	Oil, 19 feet in Trenton; second pay, 34 feet in. (L. S.)	202
.....	C.	2,133	6½	.....	.....	.....	.....	1904	Gas....	Yield, 2,500,000 feet first 24 hours.	203
W. S. Emery....	O.	140	4½	138	.....	.....	8	1904	Water .	Hard; small quantity of iron. (L.)	204
.....do	O.	120	6½	115	.....	.....	5	1904	..do	(L.)	205
.....do	O.	65	4½	62	.....	.....	4	1904	..do	(L.)	206
.....do	O.	203	8½	190	−60	.....	20	1904	..do	Soft. (L.).....	207
.....do	O.	251	5½	240	−10	.....	100	1904	..do	(L.)	208
G. W. Ward.....	....	474	....	450	.....	.....	.....	.....	..do	(L.)	209
.....	C.	105	10	.....	−10	.....	250	1900	..do	Well No. 1.....	210

Summary of well drilling

OHIO—Continued.

No.	County.	Location.	T.	R.	S.	Owner.	Contractor.
211	Montgomery ..	Dayton	.....	.....	.....	Dayton State Hospital.	Jas. Kinney, jr..
212	.....do	.....do.....	2	6	29	A. Makley.....	W. G. Teeter....
213	.....do	Miamisburg.....	.....	.....	.....	Village of Miamisburg.	.....
214	Seneca	Fostoria.....	.....	.....	.....	F. E. England	W. H. Copley...
215	.....do	.....do.....	.....	.....	.....	.....do	.....do .....
216	.....do	.....do.....	.....	.....	.....	Mrs. Flickinger...	.....do .....
217	Summit	Near N. end of Summit Lake.	.....	.....	.....	Water Works Co ..	Jas. Kinney, jr..
218	.....do	.....do.....	.....	.....	.....	.....do	.....do .....
219	.....do	Barberton.....	.....	.....	.....	Pittsburg Valve and Fittings Co.	.....do .....
220	.....do	Boston	.....	.....	.....	Harry Dayton	Dibble & Ernest.
221	Trumbull	Cortland. (Hadsell well.)	.....	.....	.....	.....	.....
222	Wayne	Orrville.....	.....	.....	.....	Cyclone Drilling Machine Co.	R. Lambie Drilling Co.
223	.....do	Orrville.....	.....	.....	.....	John Jenny	.....
a224	Wood.....	Portage. Mrs. L. Dienst farm, well No. 2.	4	11 E.	6	G. F. Munn & Son.	Frank Clough ..

OREGON.

225	Clatsop	Fort Stevens	8 N.	10 W.	5-6	United States.....	.....
226	Multnomah ...	Portland.....	.....	.....	.....	Sisters of Good Shepherd.	.....
227	Sherman	Monkland	.....	.....	.....	D. McLachlan.....	.....

PENNSYLVANIA.

228	Allegheny.....	Braddock	.....	.....	.....	Braddock Water Works.	R. H. Black.....
229	.....do	.....do.....	.....	.....	.....	William Sherwin.	.....do .....
230	.....do	Bunola.....	.....	.....	.....	Mr. Stewart	.....do .....
231	.....do	Duquesne.....	.....	.....	.....	Carnegie Steel Co.	.....do .....
232	.....do	Homestead	.....	.....	.....	.....do	.....do .....

a See detailed record at end of table.

reported in 1904—Continued.

OHIO—Continued.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute. Flow.	Yield per minute. Pump.	Year completed.	Kind of well.	Remarks.	No.
		Ft.	*In.*	*Ft.*		*Gals.*	*Gals.*				
.....	C.	.....	....	.....	.....	.....	.....	1900	Water .	Wells Nos. 2 and 3. Wells 500 feet apart, each yields 60 to 70 gallons a minute.	211
W. G. Teeter....	C.	176	5½	40	.....	.....	½	1904	..do	.....	212
J. A. Yinglin ...	M.	50	8	20	−20	.....	450	1904	..do	Water soft. Temperature 46°.	213
W. H. Copley...	C.	81	4½	79	.....	.....	.....	1904	..do	.....	214
.....do	C.	57	4½	57	.....	.....	.....	1904	..do	.....	215
.....do	C.	45	4½	44	.....	.....	.....	1904	..do	(L.)	216
.....	M.	125	....	23	.....	.....	188	1904	..do	Well No. 1. (L.)..	217
.....	M.	150	....	50	.....	.....	301	1904	..do	Well No. 2. (L.)..	218
O. D. Thomas...	C.	85	8	47	−20	.....	200	1904	..do	(L. S.)	219
.....	C.	70	5½	.....	.....	.....	4	1904	..do	.....	220
.....	M.	3,710	....	.....	.....	.....	.....	.....	..do	Little oil, gas, and salt water at 2,995 feet. Top of salt at 3,239 feet.	221
R. Lambie.....	D.	604	4½	.....	.....	.....	.....	1904	..do	Brine at 237 and 588 feet. No oil or gas. (L. S.)	222
Albert Tracy ...	D.	193	3	160	−12	.....	60	1904	..do	.....	223
Frank Clough; Evidence Kirk	O.	1,262	8¼ 6¼	1,102	.....	.....	b5	1904	Oil.....	(L. S.)	224

OREGON.

Charles Palmberg.	M.	80	6	80	−7	.....	40	1904	Water .	Water-bearing beds all the way. Water slightly irony. Temperature 52°.	225
S. Clifford.....	D.	140	....	130	.....	.....	.....	1904	..do	.....	226
James Tomlin ..	D.	195	....	.....	.....	.....	.....	1904	..do	.....	227

PENNSYLVANIA.

.....	C.	67	16	.....	−28	750	.....	1904	Water .	Test hole. (L.) ..	228
James Hoffman.	C.	102	5½	92	−55	.....	22	1904	..do	Water-bearing bed at 51 feet. Water soft. (L.)	229
.....	C.	90	....	66	.....	.....	.....	.....	..do	(L.)	230
Joseph Hufman.	C.	131	8¼	120	−38	.....	.....	1904	..do	Water-bearing beds at 69, 87, and 95 feet.	231
.....	C.	87	....	.....	.....	.....	.....	.....	..do	No. 1 test hole. (L.)	232

b Barrels a day.

Summary of well drilling

PENNSYLVANIA—Continued.

No.	County.	Location.	T.	R.	S.	Owner.	Contractor.
233	Allegheny	Homestead				Carnegie Steel Co.	R. H. Black
234	do	do				Homestead Water Works.	do
235	do	do				City of Homestead	
236	do	Pittsburg				H. S. Leighton	R. H. Black
237	do	Wilkinsburg				Texter Lumber Co.	Liberty Well Co.
238	Butler	Renfrew, Wallace farm, well No. 2.				John Humphrey & Co.	Gibson & Bovard.
239	Chester	East Downingtown				Northwood Cemetery Co.	Waterman Bros.
240	Clearfield	Dubois					J. S. Bean
241	Forest	Delight, N. P. Wheeler farm, well No. 32.				Forest Gas Co	C. E. Gesin
242	Greene	Higbee, F. B. Morris farm, well No. 1.				South Penn Oil Co.	R. D. Mead & Co.
a243	do	Higbee, L. C. Grim farm, well No. 6.				do	do
a244	do	Morris Twp., John Lewis farm, well No. 1.				Venture Oil Co	F. S. Black
245	do	Spring Hill Twp				Hope Gas Co	John McCool
246	do	Spring Hill Twp. Perry Pethel No. 1.					
247	Lawrence	Robinson Crossing				Hughes Well	
248	Montgomery	Port Kennedy				Michel Eret	Thomas B. Harper.
249	Warren	Deerfield Twp., Dallas Brooks farm, well No. 1.				Josiah G. Winger & Co.	Josiah G. Winger.
250	do	Deerfield Twp., Dell Thomas farm, well No. 1.				Stanton Oil Co	do

a See detailed record at end of table.

reported in 1904—Continued.

PENNSYLVANIA—Continued.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute. Flow.	Yield per minute. Pump.	Year completed.	Kind of well.	Remarks.	No.
		Ft.	*In.*	*Ft.*		*Gals.*	*Gals.*				
.....	C.	85	....	.....	.....	.....	.....	.....	Water .	No. 2 test hole. (L.)	233
.....	C.	70	....	.....	−23	.....	.....	.....	..do	Test well. (L.) ..	234
.....	M.	70	12	.....	.....	.....	.....	.....	..do	Series of 16 wells. (L.)	235
.....	C.	58	8–5½	.....	.....	.....	.....	1904	..do	Water-bearing beds at 40 and 52 feet. (L.)	236
E. S. Kahl.....	D.	126	....	.....	.....	.....	[b] 300	1904	..do	Water-bearing bed at 71 feet. (L.)	237
Bovard & Snider.	O.	1,780	8½–6½	.....	1,750	.....	[f] 11	1904	Oil	Water-bearing beds at 170 and 600 feet. (L. S.)	238
.....	C.	82	5½	71	.....	.....	6	1904	Water .	Water at 37 feet.	239
J. S. Bean.....	C.	3,006	....	.....	.....	.....	.....	1902	Oil	Fresh water at 110 feet; salt water at 620 and 1,430 feet. Dry hole. (L. S.)	240
R. H. McDonald; William Gesin.	D.	1,225	8-5½	80	.....	(c)	.....	1904	Gas	Hard water at 80 feet. (L. S.)	241
Jim George; W. Oslimbaugh.	M.	3,337	10–8–6–5	.....	.....	.....	.....	1904	Oil	Pittsburg coal at 1,022 feet; brine at 1,862 feet. Dry hole. (L.)	242
J. J. Reed; William Morfarty.	D.	3,076	13–10–8–6 5	2,969	.....	.....	[b] 10	1904	..do	Pittsburg coal at 927 feet. (L.)	243
H. A. Reardon; F. Bell.	D.	2,965	13–10–8–6	.....	.....	.....	.....	1904	Gas.....	Pittsburg coal at 935 feet; gas at 2,940 feet. (L.)	244
John Noels; E. J. Duck.	D.	3,434	10–8½–6½–5	.....	.....	.....	.....	1904	..do	Gas at 3,369 feet. Pressure, 900 pounds. (L.)	245
Elmer Duck....	D.	3,234	10–8½–6½–5	.....	.....	.....	.....	.....	..do	Pittsburg coal at 996 feet; gas at 3,183 and 3,228 feet. (L.)	246
.....	M.	3,830	8–6½	.....	.....	.....	.....	1904	.....	Water and oil at 240 feet; gas at 500, 575, and 825 feet. Abandoned.	247
J. B. McGuckin .	D.	581	8	530	.....	.....	130	1904	Water .	Water at 90 and 500 feet. Water hard. (L. S.	248
Jay O. Winger..	O.	831	8–5½	565	.....	.....	[b] 13	1887	Oil	Oil, gas, and salt water at 565 and 775 feet. Well abandoned. (L.)	249
.....do.....	C.	765	8–5½	728	.....	.....	[b] ¾	1896	..do	Showing of oil at 245 and 485 feet. Well pumped but a short time. (L.)	250

[b] Barrels a day. [c] 10,000 cubic feet a day.

Summary of well drilling

PENNSYLVANIA—Continued.

No.	County.	Location.	T.	R.	S.	Owner.	Contractor.
251	Warren	Deerfield Twp., John Holden farm, well No. 1.				Winger & Nichol.	Josiah G. Winger.
252	do	Deerfield Twp., Philadelphia tract, well No. 1.				do	do
253	do	Deerfield Twp., Reno land, well No. 5.				Stanton Oil Co.	do
a254	do	Eldred Twp., Adams farm, well No. 11.				do	do
255	do	Eldred Twp., Adams farm, well No. 19.				do	do
256	do	Eldred Twp., M. Cartright farm, well No. 1.				do	do
a257	do	Eldred Twp., M. Cartright farm, well No. 2.				do	do
258	do	Eldred Twp., M. Cartright farm, well No 3.				do	do
259	do	Eldred Twp., James Cochran farm, well No. 1.				Devonian Oil Co.	do
260	do	Eldred Twp., Ellis farm, well No. 6.				Stanton Oil Co.	do
261	do	Eldred Twp., Ellis farm, well No. 11.				do	do
262	do	Eldred Twp., Lamarie Lot, well No. 4.				do	E. Meely
263	do	Eldred Twp., Lamarie Lot, well No. 16.				do	Josiah G. Winger.
264	do	Eldred Twp., Lot No. 117, well No. 1.				Pardee estate	do
265	do	Eldred Twp., Philadelphia tract, well No. 1.				Tait & Paterson	do
a266	do	Eldred Twp., Philadelphia tract, well No. 2.				do	do

a See detailed record at end of table.

reported in 1904—Continued.

PENNSYLVANIA—Continued.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute.		Year completed.	Kind of well.	Remarks.	No.
						Flow.	Pump.				
		Ft.	*In.*	*Ft.*		*Gals.*	*Gals.*				
Jay O. Winger..	C.	837	8–5¼	813	.....	.....	b 1	1898	Oil	Fresh water at 100 feet; salt water at 305 feet; oil and salt water at 560 feet; gas at 807 feet. (L.)	251
J. G. and J. O. Winger.	C.	677	8–6¼	406	.....	.....	b ¼	1898	..do	Salt water at 170 feet. (L.)	252
J. O. Winger...	C.	621	8–5¼	.....	.....	.....	.....	1889	..do	Fresh water at 50 feet; oil, gas, and salt water at 315 feet; salt water at 576 feet; rose 200 feet. Abandoned. (L.)	253
J. O. and J. J. Winger.	C.	817	8–5¼	740	.....	.....	b 20	1900	..do	Salt water at 750 feet. (L.)	254
Jay O. Winger..	C.	826	8–5¼	797	.....	.....	b 20	1904	..do	Fresh water at 275 feet; oil and gas at 758 feet. (L.)	255
J. G. and J. O. Winger.	C.	499	8–5¼	482	.....	.....	b 5	1894	..do	Fresh water stratum at 435 feet. Salt water at 465 feet. (L.)	256
.....do.....	C.	477	8–5¼	449	.....	.....	b 65	1894	..do	Now (1904) producing about 2 barrels a day. (L.)	257a
J. G. Winger; W. D. Putnam.	C.	437	5¼	408	.....	.....	b 8	1895	..do	Water and gas sands end and oil sands begin at 397 feet. (L.)	258
J. G. and J. O. Winger.	C.	1,250	8¼–6¼	.....	.....	.....	.....	1898	..do	No trace of oil or gas. (L.)	259
Josiah G. Winger.	C.	421	8–5¼	389	.....	.....	b 6	1895	..do	Salt water at 358 feet. (L.)	260
J. G. and J. O. Winger.	C.	424	8–5¼	428	.....	.....	b 10	1902	..do	Fresh water, 50 to 187 feet, salt water, 187 to 213 feet. (L.)	261
.....	M.	728	8–5¼	.....	.....	.....	b 15	1899	..do	(L. S.).....	262
.....	C.	802	16–8–5¼	.....	.....	.....	.....	1904	..do	Showings of oil at 495 and 740 feet. Abandoned. (L. S.)	263
J. O. and J. J. Winger.	C.	510	8–5¼	.....	.....	.....	.....	1900	..do	Oil, gas, and salt water at 226 feet; salt water at 460; rose 200 feet. Abandoned. (L.)	264
Jay O. Winger; Charles Arters.	C.	352	5¼	.....	.....	.....	b 32	1891	..do	Drilled in 1884 by Stewart Bros., and produced 2 barrels a day. Cleaned and reclaimed in 1891.	265
Charles Arters..	C.	375	8–5¼	334	.....	.....	b 32	1891	..do	Fresh water at 100 feet; salt water at 150 feet. (L.)	266

b Barrels a day.

Summary of well drilling

PENNSYLVANIA—Continued.

No.	County.	Location.	T.	R.	S.	Owner.	Contractor.
267	Warren	Eldred Twp., Philadelphia tract, well No. 3.				Tait & Paterson	Josiah G. Winger.
268	do	Eldred Twp., Philadelphia tract, well No. 4.				do	do
269	do	Eldred Twp., Philadelphia tract, well No. 5.				do	do
270	do	Eldred Twp., Philadelphia tract, well No. 6.				do	do
271	do	Eldred Twp., Philadelphia tract, well No. 7.				do	do
272	do	Eldred Twp., Philadelphia tract, well No. 8.				do	do
273	do	Eldred Twp., W. D. Pierce farm, well No. 1.				Devonian Oil Co	do
274	do	Eldred Twp., Reno lot, well No. 6.				Stanton Oil Co	do
275	do	Eldred Twp., Reno lot, well No. 10.				do	do
276	do	Eldred Twp., Reno lot, well No. 11.				do	do
277	do	Eldred Twp., Sayers farm, well No. 18.				Rock Oil Co	J. P. Eaton
a278	do	Eldred Twp., Sayers farm, well No. 19.				do	do
a279	do	Eldred Twp., Smith farm, well No. 4.				Stanton Oil Co	Josiah G. Winger.
280	do	Eldred Twp., E. F. Thomas farm, well No. 1.				E. Thomas and T. Grant.	do
281	do	Eldred Twp., Wade farm, well No. 1.				Stanton Oil Co	do

a See detailed record at end of table.

reported in 1904—Continued.

PENNSYLVANIA—Continued.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute.		Year completed.	Kind of well.	Remarks	No.
						Flow.	Pump.				
		Ft.	*In.*	*Ft.*		*Gals.*	*Gals.*				
Charles Arters; J. O. Winger.	C.	420	8–5¼	383	.....	.....	26	1891	Oil.....	Fresh water at 152 feet; gas at 371 feet. (L.)	267
.....do.....	C.	360	8–5¼	310	.....	.....	*b* 4	1891	..do....	Fresh water 20 to 184 feet; rises nearly to surface. (L.)	268
.....do.....	C.	461	8–5¼	420	.....	.....	*b* 35	1891	..do....	Oil and water rose 200 feet in well. (L.)	269
.....do.....	C.	420	8–5¼	377	.....	.....	*b* 20	1891	..do....	Now (1904) producing about 1 barrel a day. (L.)	270
J. G. and J. O. Winger.	C.	420	8–5¼	384	.....	.....	*b* 7	1891	..do....	Proved small well. (L.)	271
.....do.....	C.	333	8–5¼	290	.....	.....	*b* 22	.....	..do....	Yield retarded by large quantity of salt water present. In this pool (Newton) oil and salt water vary proportionately. (L.)	272
.....do.....	C.	618	6¼	.....	.....	.....	.....	1898	..do....	Oil and gas at 354 feet. Casing torn by torpedo. Well abandoned. (L.)	273
Josiah G. Winger; W. D. Putnam.	C.	484	8–5¼	519	.....	.....	*b* 5	1894	..do....	Much salt water at 512 feet. (L.)	274
J. G. and J. O. Winger.	C.	554	8–5¼	.....	.....	.....	*b* 10	1899	..do....	Showing of oil not sufficient to warrant torpedoing the well. (L.)	275
Jay O. Winger..	C.	615	8–5¼	587	.....	.....	*b* 5	1904	..do....	Small showing of oil, gas, and salt water at 313 feet. (L. S.)	276
Harry Eaton; Orany Proper.	D.	544	8–6¼	514	.....	.....	*b* 15	1904	..do....	Well yields 3 barrels of salt water to 1 of oil. (L. S.)	277
H. J. Eaton; O. Proper; H. G. Peck.	D.	520	8–6¼	490	.....	.....	*b* 12	1904	..do....	Amount of salt water small. (L. S.)	*c*278
Jay O. Winger..	C.	632	8–5¼	505	.....	.....	*b* 12	1904	..do....	Fresh-water sand 140 to 220 feet. Showing of oil at 335 feet. (L. S.)	*c*279
.....do.....	C.	690	8–5¼	.....	.....	.....	.....	1901	..do....	Salt water at 425 feet. Showings of oil at 641 and 666 feet. Well abandoned. (L.)	280
Oliver Kelly....	C.	754	8	.....	.....	.....	.....	1889	..do....	Fresh water 40 to 224 feet. Slight traces of oil and gas at 712 feet. Well abandoned. (L.)	281

b Barrels a day.

Summary of well drilling

PENNSYLVANIA—Continued.

No.	County.	Location.	T.	R.	S.	Owner.	Contractor.
282	Warren	Eldred Twp., Henry Wheeler farm, well No. 1.				Stanton Oil Co.	Josiah G. Winger.
283	do	Spring Creek Twp., Frank Hellyer farm, well No. 1.				Devonian Oil Co.	do
a284	do	Southwest Twp., Sturges farm, well No. 25.				Cogswell, Thurston & Co.	B. P. McCool
a285	Washington	Thomas. Speer heirs' farm, well No. 7.				Liberty Oil and Gas Co.	Lyle & McCloy
286	York	Nashville				William Sprenkel	S. T. Crist

RHODE ISLAND.

287	Kent	Warwick				Nelson W. Aldrich	
288	Newport	Sakonnet				Edwin W. Winter	
289	Providence	Woonsocket				Alsace Worsted Co.	Artesian Well Supply Co.
290	do	do				Rev. George T. Mahoney.	C. L. Grant

SOUTH DAKOTA.

291	Gregory	Bonesteel				C. & N. W. Rwy. Co.	Matteson & Zeigler.
292	Hyde	Highmore, 8 m. NW. of.	114	71	29	Mitchell Cattle Co.	Norbeck & Nicholson.

TENNESSEE.

293	Hamilton	Chattanooga				Chattanooga Medicine Co.	

aSee detailed record at end of table.

reported in 1904—Continued.

PENNSYLVANIA—Continued.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute. Flow.	Yield per minute. Pump.	Year completed.	Kind of well.	Remarks.	No.
		Ft.	*In.*	*Ft.*		*Gals.*	*Gals.*				
Jay O. Winger..	C.	497	8-5¼	434	.....	.....	*b* ¼	1895	Oil.....	Salt water at 442 feet rose 150 feet. Oil at 465 feet. (L.)	282
J. G. and J. O. Winger.	C.	434	8-5¼	.....	.....	.....	.....	1898	..do....	Fresh water flowed 10 gallons a minute at 198 feet. Showing of oil and gas at 224 and 463 feet. Yield 5 gallons first day. Abandoned. (L.)	283
B. P. McCool, E. Hare.	C.	789	8¼-5¼	760	.....	.....	*b* 5	1904	..do....	Fresh water at 55 feet. (L. S.)	284
McCloy & Rowlee.	D.	2,275	13-10-8-6¼	2,252	.....	.....	*b* 15	1904	..do....	Water at 80 and 1,082 feet. Pittsburg coal at 336 feet. Gas at 1,285 feet. (L.S.)	285
S. T. Crist	C.	120	6	90	.....	.....	10	1904	Water .	(L.).....	286

RHODE ISLAND.

.....	M.	502	8	.....	−10	.....	120	1900	Water .	Water rather hard	287
.....	M.	66	6	50	−30	.....	¼	1904	..do....	Water soft.....	288
Frank Mentzer, M. F. Knauf.	D.	240	10-8	240	.....	.....	20	1904	..do....	(L. S.).....	289
J. F. Matthews.	C.	102	6	44	.....	.....	17	1904	..do....	(L. S.).....	290

SOUTH DAKOTA.

Matteson & Zeigler.	C.	393	5¼	.....	.....	.....	.....	1904	.....	Test hole. Water stratum 30 to 50 feet. (L. S.)	291
.....	M.	1,397	2	1,397	.....	137	.....	1902	.....	Water at 1,232 feet. Very soft. Temperature 81°.	292

TENNESSEE.

.....	O.	250	6	155	−100	.....	.....	.....	Water .	Water at 250 feet. "Abundant supply" of soft water. (S.)	293

b Barrels a day.

Summary of well drilling

TEXAS.

No.	County.	Location.	T.	R.	S.	Owner.	Contractor.
294	Bexar	Fort Sam Houston					
295	Brazoria	Sandy Point				L. B. Shephard	P. M. Granberry.
296	do	Velasco, 3½ m. SW. of				Mr. Bryan	
297	Denton	Denton				College Addition Water and Power Co.	
298	El Paso	El Paso, 40 m. N. of				Albert M. Coe	
299	do	El Paso, 25 m. N. of				J. F. Mahill and Wiley N. Coe.	
300	Hardin	Batson, Parafine Oil Co., well No. 7.				Texas Drilling Co.	Texas Drilling Co.
a301	Harris	Houston				Houston Water Co.	Gust. Warnecke.
a302	do	Humble, L. W. Long farm, well No. 1.				P. M. Granberry and others.	P. M. Granberry.
303	do	Humble, 8 m. E. of				Dan E. Kennedy	do
304	do	Humble, 6½ m. E. of				do	do
305	Jefferson	Beaumont, 17½ m. SW. of. (Bingham farm.)				Sun Co	Sun Co
306	Montgomery	Willburton				I. & G. N. Rwy	
307	Nacogdoches	Nacogdoches, 13 m. SE. of.				J. M. Thresher	
308	Nueces	Coldris, 3 m. S. of				Robert Driscoll	
309	do	do				do	
310	Tyler	Kountze, 15 m. NW. of. (Reliance No. 2.)				Sun Co	Sun Co
311	Wilson	Sutherland Springs, Lee farm, well No. 1.				American Mineral Co.	American Mineral Co.

a See detailed record at end of table.

reported in 1904—Continued.

TEXAS.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute. Flow.	Yield per minute. Pump.	Year completed.	Kind of well.	Remarks.	No.
		Ft.	*In.*	*Ft.*		*Gals.*	*Gals.*				
.....	M.	726	....	705	−5	.....	200	1901	Water .	Water-bearing beds at 351 and 398 feet. Water at 398 feet salt. (L. S.)	294
.....	C.	1,500	....	.....	.....	.....	.....	1904	Oil.....	Prospect well. Artesian water stratum 1,000 to 1,100 feet.	295
R. T. Clifton....	D.	742	....	.....	.....	.....	.....	1904	..do....	Abandoned at 742 feet. (L. S.)	296
Luther Myers ..	M.	592	6–4	520	.....	.....	12	1904	Water .	(L. S.)	297
James Sewell...	M.	160	5–6	45	.....	.....	.....	1898	..do....	"Abundant supply" of soft water.	298
.....do	M.	350	6	335	.....	.....	.....	1904	..do....	Soft water	299
Joseph Dronot..	M.	885	4	.....	.....	.....	[b]50	1904	Oil.....	(L. S.)	300
A. Warnecke ...	O.	2,025	8–6 / 4	.....	.....	.....	.....	1904	Water .	Gas at 1,600 feet. One of a series of wells which yield from 1,000 to 800,000 gallons a day each. (L. S.)	301
W. A. Young....	C.	990	11¼ / −6	950	.....	.....	[b]100	1904	Oil.....	Gas present in increasing amounts below 600 feet. (L. S.)	302
.....	C.	1,500	....	.....	.....	.....	.....	1904	..do....	Prospect well; no oil. Little gas at 600 feet. Water-bearing beds 600 to 650 feet and 1,150 to 1,200 feet.	303
.....	C.	1,000	6–2¼	.....	.....	.....	.....	1904	..do....	Prospect hole. Found neither oil nor gas.	304
James W. Clark.	D.	1,515	6–4	.....	.....	.....	.....	1904	..do....	Water at 220 and 260 feet. Gas at 240 and 400 feet. Dry hole. (L.)	305
J. H. Lee	D.	917	....	892	.....	.....	[b]50	1904	..do....	.....	306
.....	O.	435	6	.....	.....	.....	.....	1904	..do....	Water at 68 and 393 feet. Oil at 212, 312, 328, and 360 to 428 feet. Lost on account of water. (L. S.)	307
Thomas Fowler.	D.	590	5¾ / 4¼	.....	.....	80	.....	.....	Water .	Well No. 4. (L.).	308
.....do	D.	625	5¾ / 4¼	.....	.....	150	.....	.....	..do....	Well No. 5. (L.).	309
James W. Clark.	O.	1,737	6–4	.....	.....	.....	.....	1904	Oil	Dry hole. (L.)...	310
Hamrick; Pannewitz; Donohue.	D.	1,500	....	.....	.....	.....	.....	1904	..do....	Flowing water and gas strata at 14, 71, 419, 973, 1,056, and 1,352 feet. Traces of oil at 415, 628, 775, and 1,352 feet. Dry hole. (L.)	311

[b] Barrels a day.

Summary of well drilling

UTAH.

No.	County.	Location.	T.	R.	S.	Owner.	Contractor.
312	Beaver	Beaver				W. Shepherd	
313	Boxelder	Brigham	9	3	14	W. O. Knudson	
314	Davise	Farmington				Guffy & Galey	Guffy & Galey
315	Iron	Lund				San Pedro, Los Angeles and Salt Lake R. R. Co.	L. J. Craig

VIRGINIA.

316	Henrico	Richmond				Lewis Ginter	

WASHINGTON.

317	King	Ballard				City of Ballard	

WEST VIRGINIA.

a318	Kanawha	Forks of Little Sandy. O. Simmons farm, well No. 1.				Lehigh Oil Co	Weller Bros
319	Ohio	Wheeling				News Publishing Co.	Jas. Kinney, jr.
a320	Ritchie	Harrisville, F. D. Hawkins, No. 1.				Octo Oil Co	B. W. Publes
321	Tyler	Van Camp				Lincoln District	Watkins & Co
322	Wetzel	Folsom. John Robison farm, well No. 17.				South Penn Oil Co.	W. S. Burton
a323	do	Hundred. J. Murphy farm, well No. 1.				Syndicate Oil Co	Reese, Heasley & Meals.
324	do	Keough				Hope Natural Gas Co.	John P. Fishel
325	do	Keough. J. V. Higgins farm, well No. 1799.				Philadelphia Co	do

a See detailed record at end of table.
c See detailed record in paper on "Oil and Asphalt Prospects in Salt Lake Basin," by J. M. Boutwell: Contributions to Economic Geology, 1904.

reported in 1904—Continued.

UTAH.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute. Flow.	Yield per minute. Pump.	Year completed.	Kind of well.	Remarks.	No.
		Ft.	*In.*	*Ft.*		*Gals.*	*Gals.*				
Geo. G. Halterman.	D.	330	....	.....	.....	.....	.....	1904	Water .	Not flowing	312
.....	M.	30	9	22	−22	.....	300	1904	..do	Dug well 9 feet in diameter.	313
....	O.	2,000	....	.....	.....	.....	.....	.....	Oil	Dry. Well did not reach bed rock.	314
.....	C.	584	12–10–8–6	573	.....	.....	50	.....	Water .	Salt water at 12 feet. (L.)	315

VIRGINIA.

.....	M.	445	....	410	.....	.....	.....	.....	Water .	A little water at 102 feet. (L.)	316

WASHINGTON

G. P. James	M.	245	....	.....	.....	.....	.....	1904	Water .	.....	317

WEST VIRGINIA.

J. G. and G. J. Weiler.	D.	1,700	13–10–8–6¼	.....	.....	(*d*)	.....	1904	Gas	Fresh water at 60 and 155 feet. Hole flowed full of salt water 940 to 990 feet. Gas at 928 feet. (L. S.)	318
.....	C.	250	....	.....	.....	.....	.....	1904	Water .	(L. S.)	319
.....	O.	1,875	....	.....	.....	*b* 12	.....	1904	Oil	(L. S.)	320
.....	C.	36	6	35	−13	.....	.....	1904	Water .	Soft.	321
H. A. Reardon ..	D.	3,560	10–8–6–5	.....	.....	.....	*b* 100	1902	Oil	Pittsburg coal at 1,435 feet. Salt water at 2,225 and 2,735 feet. Oil at 3,512 and 3,542 feet. Deepest producing well known. (L.)	322
E. J. Akins; A. Wild.	D.	3,236	13–10–8¼–6¼	.....	.....	(*d*)	.....	1904	Gas	Pittsburg coal at 1,852 feet. Gas at 1,995, 2,145, and 3,000 feet. Yield. (L. S.)	323
T. L. Dunlap; C. L. King.	D.	2,635	13–10–8–6	.....	.....	.....	.....	1902	..do	Water at 60 feet. Pittsburg coal at 530 feet. Gas at 1,675, 1,885, and 2,615 feet. Rock pressure of gas at 1,675 feet, 800 pounds. (L.)	324
.....do	D.	3,200	10–8–6¼	.....	.....	.....	.....	1904	..do	Pittsburg coal at 1,095 feet. Gas at 1,866 and 2,460 feet. Salt water at 1,935 feet. Dry hole. (L.)	325

b Barrels a day. *d* 500,000 cubic feet a day.

Summary of well drilling

WEST VIRGINIA—Continued.

No.	County.	Location.	T.	R.	S.	Owner.	Contractor.
326	Wetzel	Van Camp				J. G. Eddy	Watkins & Co.
327	do	do				Magnolia district.	do
328	do	do				J. M. Van Camp	do
329	do	do				Z. S. Watkins	do
330	do	do				Watkins & Co	do

WISCONSIN.

331	Brown	Askeaton	21	20	30	Cheese factory	J. J. Faust
332	do	do	21	20	22	John Hart	do
333	do	Mills Center				Jef. Kimbs	
334	Columbia	Arlington				David Bullen	
335	Fond du Lac	Eden Twp			33	Academy of St. Mary.	P. Roughen
336	do	Fond du Lac				M. Obrin	do
337	do	do				Charles Olem	do
338	do	Waupun					W. F. Sealy
339	Grant	Castlerock	7 N.	1 W.	14		H. G. Gorder
340	Iowa	Highland	7	1	17		do
341	Juneau	Mather				Appleton Cranberry Co.	E. R. Vandervort.
342	Outagamie	Dale	21	15	30	Conrad Giebel	I. W. Hills
343	do	Greenville	22	17	19	Charles H. Fischer	do
344	do	Hortonville	22	16	36	W. Fischer	do
345	do	do	22	16	13	Anthony Wallace	do
346	do	Medina	21	15 E.		M. Bottrell	do
347	do	do	21	15	26	Sam Rupple	do
348	do	Shiocton	43	16	36	John Laird	do
349	do	South Kaukauna					
350	Racine	Corliss	3	22	9	T. F. Cooney	W. M. Bolles
351	do	Franksville	4	22 E.	28	F. Kittenhoffen	do
352	Vernon	Valley	14	2 W.	26	Frank Winchel	
353	Walworth	Whitewater. (City waterworks.)				C. E. Gray	W. L. Thorne & Co.
354	Waukesha	Elm Grove	7	20	35	C. K. Reichert	Peter Bauer
355	Winnebago	Larsen	20	16 E.	21	John Lemke	I. W. Hills
356	do	do	20	16 E.	21	Fred Ziehm	do
357	do	Winneconne	19	15	2	George Barber	do

WYOMING.

358	Sweetwater	Rock Springs, 6 m. S. of.	18	104W.	20	Belgo American Drilling Co.	

reported in 1904—Continued.

WEST VIRGINIA—Continued.

Driller.	Authority.	Depth.	Diameter.	Depth to principal water or oil supply.	Height of water.	Yield per minute.		Year completed.	Kind of well.	Remarks.	No.
						Flow.	Pump.				
		Ft.	*In.*	*Ft.*		*Gals.*	*Gals.*				
.....	C.	137	6	.....	−97	.....	.....	1904	Water.	Soft water at 70, 126, and 137 feet.	326
.....	C.	41	5¼	36	− 8	.....	.....	1904	..do	Soft water	327
.....	C.	31	6	27	−10	.....	.....	1904	..do	.....do	328
.....	C.	60	6	55	−20	.....	.....	1904	..do	.....do	329
.....	C.	32	6	22	−10	.....	.....	1904	..do	.....do	330

WISCONSIN.

M. G. Faust	C.	534	4¼	512	−75	.....	7	1904	Water.	(L. S.)	331
.....do	C.	117	4¼	110	.....	.....	10	1904	..do	.....	332
Chas. L. Green..	D.	315	.....	.....	.....	.....	.....	1904	..do	(L. S.)	333
Thos. Eagen	D.	155	.....	.....	.....	.....	.....	1904	..do	(L. S.)	334
P. Roughen	C.	97	5	75	.....	.....	.....	1904	..do	.....	335
.....do	C.	95	5	93	.....	.....	12	1904	..do	(L.)	336
.....do	C.	228	5	227	.....	.....	15	1904	..do	(L. S.)	337
.....	C.	800	6–5	.....	.....	.....	.....	1887	..do	(L. S.)	338
H. G. Gorder....	C.	162	7¼	130	.....	.....	5	1904	..do	(L. S.)	339
.....do	C.	265	6¼	.....	.....	.....	.....	1904	..do	Stratum at 240 feet yields sulphur water.	340
E. R. Vandervort.	C.	179	6	.....	.....	.....	.....	1904	..do	(L. S.)	341
J. Yahuke and F. Sweet.	C.	35	4	35	.....	.....	.....	1904	..do	"Good stream of water."	342
G. H. Fischer and F. Sweet.	C.	117	4	116	− 5	.....	.....	1904	..do	(L. S.)	343
.....do	C.	41	4	35	.....	.....	.....	1904	..do	(L.)	344
.....do	C.	105	4	100	.....	.....	.....	1904	..do	.....	345
F. Sweet	C.	23	4	.....	.....	.....	.....	1904	..do	.....	346
R. Haase and Wescott.	C.	87	....	70	.....	.....	.....	....	..do	.....	347
G. H. Fischer and M. Hills.	C.	150	4	150	.....	.....	.....	1904	..do	.....	348
J. J. Faust.....	D.	300	4¼	.....	−60	.....	3	1904	..do	(S.).....	349
H. Jorgensen...	D.	94	4	.....	.....	.....	15	1904	..do	(L. S.)	350
.....do	D.	98	4	98	.....	.....	25	1904	..do	(L. S.)	351
B. I. Baley & Son	M.	280	6–5¼	230	.....	.....	3	1904	..do	(L. S.)	352
W. L. Thorne & Co.	C.	252	6	200	.....	30	250	1904	..do	Water at 71 feet, rose to 2 feet. (L. S.)	353
H. M. Knaack..	D.	190	6	170	.....	20	.....	1904	..do	Water from 170 to 190 feet.	354
J. Yahnke.....	C.	38	4	28	.....	.....	.....	1904	..do	Pumps small stream.	355
John Yahnke and F. Sweet.	C.	114	4	107-	−60	.....	.....	1904	..do	(L.)	356
J. Yahnke and M. Hills.	C.	98	4	.....	.....	.....	.....	1904	..do	.....	357

WYOMING.

L. J. Craig.....	D.	2,400	13	.....	.....	.....	.....	1904	Oil	Water-bearing bed at 30 and 90 feet. Small showing of oil at 625 feet.	358

DETAILED RECORDS.

The detailed reports which follow were selected because they give definite stratigraphic information or information of importance in drilling adjoining wells. While only such records were chosen as appeared to have been kept with care, the Survey does not guarantee their accuracy. Descriptions are given substantially as presented in the original records, although the compiler has taken the liberty to make some changes in nomenclature, such as substituting shale for "soapstone," and to make other modifications in favor of uniformity and conciseness. When the samples suggest an interpretation radically different from the one in the driller's log, both are given, with the former in parentheses. Other interpolations made on the authority of the compiler are also bracketed.

13. Well near Seaside, Monterey County, Cal.

[Authority, B. N. Baker, owner.]

	Feet.
Surface soil	0– 10
Water sand	10– 40
Quicksand	40– 60
Gray sand	60–120
Adobe clay	120–136
Blue clay	136–148
Sandy shale	148–155
Hard shale	155–156
Blue shale	156–173
"Chalk rock"	173–183
Blue shale	183–240
Hard shale	240–241
Blue shale	241–253
Yellow clay and sand	253–263
Cobblestone, gravel, and water	263–270
Water sand	270–303
Blue shale	303–315
"Chalk rock"	315–338
Sandy shale	338–425
Blue clay	425–441
Sand and shale	441–468
Blue clay	468–490
Sand and shale	490–513
Yellow clay	513–518
White sand, carrying some water	518–540
Yellow clay	540–560
Blue shale	560–581
Sand and gravel	581–610
Hard shale; shell	610–617

Last entry is probably incorrect. Water was struck at 610 feet, after piercing shell and going with drill into water sand; flow, 30 gallons a minute.

14. Well on Pueblo Lot 146, Point Loma, San Diego County, Cal.

[Begun August 18, 1900; completed March 18, 1901. Authority, Katherine Tingley, owner.]

[Elevation of mouth of well, 255.88 feet above high tide.]

	Feet.
Surface clay	0– 3
"Hardpan"	3– 8
Sandy clay	8– 30
Water-bearing sand	30– 40
Sandy shale and dry sand	40– 60
Sandy shale	60–100
Sand	100–106
Dark-blue shale	106–190
Water-bearing sand	190–192
Dark-blue shale	192–200
Water-bearing sand	200–202
Dark-blue shale	202–260
Whitish clay	260–261
Coal	261–262
"Ore"	262–265
Water-bearing sand, good water	265–271
Dark-blue shale	271–298
Water-bearing sand	298–300
Dark-blue shale	300–320
White quartz. } gold colors from panning {	320–321
Blue granite .. } gold colors from panning {	321–323
Light-blue shale	323–350
Alternate shale and sand	350–360
Light-blue shale	360–370
Water-bearing sand	370–372
Light-blue shale	372–388
Water-bearing gravel and sand	388–390
Shale, gravel, and clay	390–400

Point Loma is an isolated cretaceous summit, according to the State Mining Bureau, and the above log shows the geologic column of its undisturbed strata. Diameter of well, 6 inches, 0 to 40 feet; 5 inches, 40 to 400 feet. Water level, 253 feet below surface, or 2.88 feet above high tide. Estimated yield, 35,000 gallons daily if all water-bearing strata are used.

22. Well at Lajunta, Otero County, Colo.

[Samples furnished by La Junta Oil and Gas Company.]

	Feet.
Clay	800–1,080
Sandstone and limestone	1,230–1,290
Light-red sandstone and limestone	1,300–1,500
Dark-red sandstone—limy	1,500–1,535
White sandstone	1,535–1,600
Red sandstone	1,600–1,612
Red sandstone and gray limestone	1,612–1,660
Red sandstone and limestone	1,660–1,703

42. Well at Belvidere, Boone County, Ill.

[Begun April 9, 1903; completed May 23, 1903. Authority, H. W. Hambrecht, driller.]

	Feet.	
Quicksand	0 –	40
Fine gravel	40 –	90
Coarse gravel	90 –	122.5
Gray limestone	122.5–	355
St. Peter's sandstone, coarse and honeycombed, water-bearing	355 –	574
Red marl and limestone	574 –	608
Brown limestone	608 –	643
Brown shale	643 –	718
Sandstone—water of good quality	718 –	834
Red marl	834 –	854
Blue shale	854 –	984
White sandstone, honeycombed rock, water-bearing	984 –	1,070
Blue shale	1,070 –	1,168
Postdam sandstone, soft water	1,168 –	1,231

Well ended in blue shale. Total depth, 1,231 feet. Ten-inch drive-pipe, 0 to 125 feet; diameter of hole 8 inches from 125 to 608 feet; 6¼ inches from 608 to 1,231 feet.

46. Well at Naperville, Dupage County, Ill.

[Begun August 31, 1903; completed January 19, 1904. Authority, H. W. Hambrecht, driller.]

	Feet.	
Black soil	0–	4
Sand and gravel	4–	10
Blue shale	10–	18
Loose rolling rock	18–	21
White limestone	21–	237
Blue shale	237–	320
White limestone	320–	646
St. Peter's sandstone; water, hard and soft in streaks	646–	792
Blue shale	792–	836
Brown limestone	836–	950
Blue shale	950–	1,152
Gray limestone—water-bearing rock full of crevices	1,152–	1,425

Ten-inch drive pipe from 0 to 117.5 feet; diameter of hole, 8 inches from 117.5 to 836 feet; 6¼ inches from 836 to 1,425 feet.

47. Well in SE. ¼ of NW. ¼ sec. 32, T. 15 N. (1½ miles west of Kewanee), Henry County, Ill.

[Begun September 9, 1904, completed November 21, 1904. Record and samples furnished by L. Nichols, driller. Geologic divisions made by E. O. Ulrich.]

	Feet.	
Yellow clay	0 –	10
Yellow clay, sandy	10 –	20
Lower Pennsylvania coal measures:		
Blue sandy clay	20 –	36
Soft drab shale	36 –	85
Coal	85 –	86.5
Soft drab shale	86.5–	92.5
Hard gray sandstone	92.5–	93.5
Soft drab shale	93.5–	172
Coal and shale	172 –	184
Coal	184 –	187

	Feet.		
Lower Pennsylvania coal measures—Continued.			
Soft dark shale	187	–	202
Hard dark sandstone	202	–	202.5
Soft gray shale mixed with lime	202.5	–	238
Soft black shale; with pyrite 282–301	238	–	308
Gray sandy shale	308	–	322
Gray sandy limestone	322	–	352
Devonian and Silurian limestone:			
Hard gray limestone	352	–	650
Light-blue limestone	650	–	670
White limestone	670	–	730
Gray limestone	730	–	760
Maquoketa:			
Light-green shale	760	–	833
Hard gray limestone	833	–	850
Hard light-green shale	850	–	915
Hard brown shale	915	–	940
Hard drab shale	940	–	949
Galena limestone:			
Dark-brown limestone	949	–	970
Gray limestone	970	–	1,030
Brown and white limestone	1,030	–	1,050
Brown limestone	1,050	–	1,073

Rig used, pole tools. Diameter of well, 12 inches 0 to 174 feet; 10½ inches 174 to 352 feet; 8⅝ inches 352 to 954 feet; 6 inches from 954 to 1,073 feet. Hole practically dry to 475 feet, where water rose to within 300 feet of mouth of well. Water fresh, no great amount. Main supply from 954 to 1,073 feet. Well pumps 80 gallons a minute.

52. Well at Streator, Lasalle County, Ill.

[Begun September 5, 1902; completed November 15, 1902. Authority, H. W. Hambrecht, driller.]

	Feet.		
Yellow clay	0	–	5
Shale	5	–	8
Coal	9	–	13.5
Shale	13.5	–	15
Brick and tile clay	15	–	20
Blue shale	20	–	90
Blue and brown shale	90	–	95
Coal, good quality	95	–	99.5
Blue shale	99.5	–	172.5
Brown and blue shale	172.5	–	185
Coal, best	185	–	187
Brick and tile clay	187	–	195
White limestone	195	–	385
St. Peter's sandstone; water in lower part not good	385	–	596
Blue shale	596	–	620
Brown limestone; very good water	620	–	706
Madison sandstone; slightly salty water	706	–	834
Brown limestone; soft water	834	–	1,056
Sandstone; water	1,056	–	1,096
Limestone	1,096	–	1,115

Eight-inch pipe from 0 to 195 feet; 6-inch pipe from 0 to 620 feet; 6-inch hole from 620 to 1,115 feet.

62. Well No. 1, on G. S. Whitehair farm, in SE. ¼ of SE. ¼ sec. 24 (4 miles SE. of Albany), Delaware County, Ind.

[Begun October 11, 1904, completed October 31, 1904. Authority, William Jameson, driller.]

	Feet.
Soft black soil	0– 10
Hard dark limestone	10– 45
Soft red shale	45– 60
Gray limestone of varying hardness	60– 200
Soft shale (calcareous)	200– 220
Hard blue limestone	220– 260
Soft light shale	260– 280
Hard dark limestone and shale	280– 300
Hard blue limestone	300– 340
Soft light shale	340– 500
Soft brown shale	500– 600
Soft light shale	600– 700
Soft dark shale	700– 800
Soft brown shale	800– 950
Trenton limestone	950–1,260

Some gas at top of Trenton. Well finished at 1,262 feet with little show for oil. Shot with 200 quarts of glycerine. Diameter of well, 8 inches from 65 to 340 feet; 6¼ inches from 340 to 1,262 feet. Casing inserted at 340 feet. Principal water-bearing strata between 30 and 320 feet.

64. Well No. 5, on the Hoppis heirs' farm, in sec. 24, T. 12 E. (one-half mile east of Redkey), Jay County, Ind.

[Begun October 10, 1904, completed November 5, 1904. Authority, Bert Gilbert, driller.]

	Feet.
Soft brown clay	0– 40
Soft blue clay	0– 100
Hard yellow limestone	100– 120
Hard gray limestone	120– 180
Soft gray shale, "brake"	180– 240
Hard gray limestone	240– 260
Soft gray shale, "brake"	260– 300
Hard gray limestone	300– 320
Soft gray shale (brownish, 800–840)	320– 960
Trenton limestone; gas, pay 960–980; oil sand, 1,360–1,385	960–1,385

Principal water stratum in limestone at depth of 153 feet. Amount of oil obtained, 5 barrels.

69. Well at Cherokee State Hospital, in sec. 28, T. 92, R. 40 (1½ miles NW. of Cherokee), Cherokee County, Iowa.

[Completed February 24, 1902. Authority, Cherokee State Hospital.]

	Feet.
Loam	0– 4
Yellow clay	4– 60
Blue clay	60–240
Quicksand; water	240–255
Gravel; water	255–260
Quicksand; water	260–270
Blue clay	270–355

	Feet.
Sandstone; water	355– 375
Shale	375– 385
Pink shale	385– 400
Gravel; water	400– 405
Gray shale	405– 410
Red shale	410– 430
Gray limestone; water between 430 and 435	430– 450
Gray shale	450– 470
Gray limestone; water between 470 and 475	470– 480
Shale	480– 490
Limestone	490– 505
Sandstone	505– 510
Shale	510– 525
Sandstone; water	525– 535
Limestone; water rose 30 feet from crevice in rock between 725 and 735 feet	535– 965
Shale	965–1,015
Sandstone; at 1,075 feet water rose 970 feet	1,015–1,095
Shale	1,095–1,100
Gypsum	1,100–1,120

Diameter of well, 12 and 9 inches; 6-inch pump casing 500 feet down. Depth of principal source of water, 1,120 feet. Water rises to within 206 feet of mouth of well. Yield, 100,000 gallons in twenty-four hours.

70. Well at Burlington, Des Moines County, Iowa.

[Begun August 22, 1904; completed October 12, 1904. Authority, R. J. Johnston, driller.]

	Feet.
Artificial filling	0– 10
Yellow clay	10– 20
Blue clay	20– 60
Sand	60– 66
Blue clay	66– 72
Soft limestone	72– 75
Soft gray shale	75– 85
Soft blue shale	85–154
Soft black shale	154–160
Gray shale	160–190
Soft dark shale	190–260
Soft gray shale	260–280
Hard blue limestone	280–305
Hard gray limestone	305–325
Soft gray shale (limestone)	325–335
Hard gray limestone	335–355
Hard red "granite" (limestone containing pyrite)	355–400
Soft blue limestone	400–410
Soft red limestone	410–425
White "magnesia" (clayey limestone)	425–435
Soft "water rock" (no samples below 430)	435–507

Rig used, Keystone driller. Diameter, 5§ inches from 0 to 507 feet. Length of casing, 76 feet. Main water supply from 435 to 507 feet. Flows 45 gallons per minute. Pressure, 16½ pounds.

71. Well at Davenport, Scott County, Iowa.

[Begun March 10; completed July 8, 1904. Authority, H. W. Hambrecht, driller.]

	Feet.	
Surface sand	0–	24
Blue shale	24–	89
Black shale	89–	90
Blue shale	90–	110
Loose rock	110–	113
Brown limestone	113–	270
Blue shale	270–	275
Limestone	275–	418
White shale	418–	644
Brown limestone; flow from crevice, about 80 gallons a minute	644–	970
Blue shale	970–	996
Sandstone, St. Peter's; flow increased to 210 gallons a minute	996–1,	050
Brown limestone; flow increased to 310 gallons a minute	1, 050–1,	300

Ten-inch casing from 0 to 110 feet, 8-inch casing from 0 to 120 feet, 8-inch hole from 120 to 1,300 feet.

78. Well at Horace (4 miles east of the Kansas-Colorado State line), Greeley County, Kans.

[Begun February 19, 1901; completed November 26, 1901. Authority, E. Fisher, engineer B. & B.]

	Feet.	
Cemented gravel mixed with clay and lime	0–	55
Clay, gravel, and lime mixed	55–	100
Gray shale	100–	550
White limestone	550–	620
Brown shale; water at 825 rose 400 feet	620–1,	050
Sandstone, more or less broken; top of first Dakota	1, 050–1,	095
Gray sandstone	1, 095–1,	110
Reddish brown sandstone, broken, very much so, 1,130–1,148	1, 110–1,	148
Sandstone; bottom of first Dakota	1, 148–1,	160
Shale	1, 160–1,	250
Reddish brown sandstone, more or less broken; second Dakota water rose 800 feet from 1,325 feet	1, 250–1,	325
Shale	1, 325–1,	370

Water obtained from Dakota sandstone. In pumping the well for several months the water which originally stood at a level of about 830 feet below the ground line was lowered gradually to about 1,000 feet below the ground line, and the difficulty in pumping the limited amount of water (about 30 gallons a minute) was so great that the well was abandoned.

80. Well No. 3 on the Robb farm, SE. ¼ of SE. ¼ of T. 25, R. 12 (near Neal), Greenwood County, Kans.

[Begun October 8, 1904; completed November 12, 1904. Authority, F. R. Gammon, owner.]

	Feet.	
Soil and clay	0–	20
Gravel	20–	30
Blue clay	30–	60
Limestone	60–	80
Blue shale	80–	103
Limestone	103–	126
Blue shale	126–	141

	Feet.
Red shale	141–154
Blue shale	154–171
Limestone	171–187
Shale	187–234
Limestone	234–238
Shale	238–285
Sandy shale	285–308
Blue shale	308–345
Limestone	345–348
Shale	348–350
Limestone	350–363
Sandstone; water	363–381
Shale	381–386
Blue shale; 8¼ inch casing	386–505
Limestone	505–550
Soft limestone; had to put in water to drill	550–560
Limestone; 15 feet soft	560–596
Hard limestone	596–645
Limestone	645–655
Blue shale	655–675
Limestone	675–685
Sandy shale	685–700
Blue shale	700–792
Very hard limestone	792–812
Blue shale	812–842
Limestone; water	842–882
Sandstone	882–902
Limestone; strong odor of oil	902–920
Black shale	920–927
Limestone	927–932
Oil sand	932

83. Well No. 1, on the Logan farm, W. ½ SW. ¼ sec. 27, T. 33, R. 15 (9 miles south of Independence), Montgomery County, Kans.

[Begun April 25, 1904; completed May 13, 1904. Authority, A. J. Yoke, owner.]

	Feet.
Surface soil	0– 15
Shale and lime shell	15–120
Limestone	120–135
Dark shale	135–140
Gritty shale	140–165
Limestone	165–175
Shale (limy)	175–220
Limestone	220–260
Sandstone; water and gas	260–275
Shale	275–330
Limestone	330–335
Shale (limy)	335–465
Limestone	465–495
Shale (limy)	495–525
Limestone	525–535
Shale	535–540
Limestone	540–555

	Feet.
Shale	555– 585
Sandstone; water	585– 640
Gritty shale	640– 680
Limestone	680– 705
Black shale	705– 710
Shale (limy)	710– 725
Gray sand; oil	725– 730
Gritty shale	730– 740
Gray sand	740– 760
Black shale	760– 783
"Big lime"	783– 818
Black shale	818– 825
Limestone	825– 853
Shale, gas and water	853– 855
Limestone	855– 875
Black shale	875– 885
Sandstone; water	885– 895
Shale (limy)	895– 955
Dark shale	955– 965
Gritty shale (limy)	960– 990
Shale	990–1,005
Shale (limy)	1,005–1,080
Dark limestone	1,080–1,115
Sand; gas	1,115–1,118
Hard gritty shale	1,118–1,142
Sandstone; gas	1,142–1,160

Yield first twenty-four hours, 18,000,000 feet; initial pressure, 480 pounds. Forty-one feet of 8¼-inch casing, 950 feet of 6¼-inch casing.

84. Well No. 22, on the S. Smith farm, SE. ¼ of SE. ¼ sec. 10, T. 27, R. 18 (2 miles NE. of Chanute), Neosho County, Kans.

[Begun November 9; completed November 27, 1904. Authority, J. F. Allen, field manager for I. N. Knapp.]

	Feet.
Surface soil	0– 20
Brown gravel; fresh water	20– 30
Hard gray limestone	30– 56
Sandstone	56– 61
Hard gray limestone	61– 65
Soft gray shale	65– 70
Hard gray limestone	70– 75
Soft gray sandstone	75– 80
Soft gray limestone	80–115
Soft gray shale (limy)	115–125
Soft gray limestone; 4 barrels water an hour at 128 feet	125–130
Hard gray limestone	130–142
Soft gray shale (limy)	142–320
Soft light-gray limestone	320–335
Soft gray shale (limy)	335–370
Gray sandstone; salt water and gas; hole filled up 200 feet	370–385
Soft gray shale (limy)	385–400
Soft gray limestone	400–420
Shale	420–428

	Feet.
Hard gray limestone	428–458
Soft gray shale (limy)	458–490
Hard gray limestone	490–513
Hard black shale (limy); water, 40 barrels an hour	513–521
Hard gray limestone	521–528
Soft gray shale (limy)	528–715
Soft gray shale (sandy); top of sand, showing of oil	715–720
Soft gray sandstone and shale (limy)	720–728
Sandstone; oil sand, 22 feet of pay at bottom	728–752

Yield, 4 or 5 barrels a day. Length of casing, 623 feet; diameter, 5 inches.

122. Well 1 mile north of Bay St. Louis, Hancock County, Miss.

[Begun October 29; completed November 20, 1904. Authority, John L. Ford, driller.]

	Feet.
Blue sandy clay	0– 10
White sand	10– 60
Yellow sand	60– 95
White sand and gravel	95–145
Green clay	145–160
Gray sand	160–220
Green clay	220–350
Gray sand	350–370
Green clay	370–650
Water sand; flows 50 gallons a minute	650–690
Blue clay	690–818
Water sand; flows 225 gallons a minute	818–897

Diameter of well, 3 inches.

126. Well 1½ miles northwest of Moss Point, Jackson County, Miss.

[Begun October 3, 1904; completed October 12, 1904. Authority, John L. Ford, driller.]

	Feet.
Hard yellow clay (sandy)	0– 20
Yellow sand	20– 35
Clay (sandy, variegated)	35– 50
Sand (fine white)	50–100
Sand (coarse, white)	100–140
Clay (sandy)	140–210
Sand (fine white)	210–220
Clay	220–370
Sand (fine, white)	370–390
Clay	390–710
Sand (fine gray)	710–790
Clay	790

Main water supply, 770 to 790 feet. Yield, 135 gallons per minute.

127. Well at Moberly, Randolph County, Mo.

[Authority, A. P. Phillips, driller and manager.]

	Feet.
Clay and quicksand	0–115
Blue sandstone	115–127
Blue and white sandstone	127–132
Gray sandstone	132–137
Blue flint	137–146

	Feet.
Blue and white flint	146–154
Yellow flint	154–160
Yellow sandstone	160–170
Hard white sandstone	170–178
Gray sandstone	178–186
Gray sandstone and white flint	186–191
Yellow sandstone	191–202
Hard white flint	202–210
Yellow flint	210–218
Blue flint	218–226
Yellow flint	226–230
Blue and white flint	230–250
White flint	250–260
Blue flint	260–263
White and brown flint	263–266
Brown flint	266–269
White sandstone	269–272
Blue sandstone	272–275
Blue and white sandstone	275–278
White sandstone	278–281
Light-gray sandstone	281–289
Light-brown sandstone	289–290
Dark-brown sandstone	290–320
Gray sandstone	320–345
White sandstone	345–355
White and yellow sandstone	355–380
Gray sandstone	380–430
Dark-gray sandstone	430–447
Green shale	447–450
Dark coarse sandstone	450–460
Dark-gray sandstone	460–470
Gray sandstone	470–480
Green shale and gray sandstone	480–490
Light and dark sandstone	490–510
Dark-gray sandstone	510–520
Black sandstone	520–560
Brown sandstone	560–570
Dark-gray sandstone	570–580
Gray sandstone	580–590
White limestone	590–600
Dark-gray sandstone	600–607
Green shale	607–612
Gray sandstone	612–632
White gravel, like glass sand; great quantity of good water	632–685
Gray sandstone	685–693
Green sandstone	693–705
White and gray sandstone	705–709
Gray sandstone	709–722
Brown sandstone	722–772
Light-brown sandstone	772–802
Gray sandstone	802–832
Brown sandstone	832–840
Light-brown sandstone	840–850

	Feet.
Clear white water sand; salt water at 870 feet	850– 870
Light-gray sandstone	870– 960
Brown sandstone	960–1,020
Dark-brown sandstone	1,020–1,045
Fine brown sandstone	1,045–1,100
Black and brown sandstone	1,100–1,115
Light-gray sandstone	1,115–1,150
Gray sandstone	1,150–1,170
White and gray sandstone; magnesia water at 1,180 feet	1,170–1,190
Yellow and white sandstone	1,190–1,200
Dark-gray sandstone	1,200–1,210
Black and white sandstone	1,210–1,215
Gray sandstone; very salty water at 1,215 feet	1,215–1,220
Blue and white flint	1,220–1,225
Crevice and pebbles	1,225–1,230
Blue and gray sandstone	1,230–1,240
Fine white sandstone	1,240–1,260
White flint	1,260–1,290
Blue and gray sandstone	1,290–1,300
Dark-gray sandstone	1,300–1,330
Gray sandstone	1,330–1,440
Yellow and white sandstone	1,440–1,450
Blue sandstone	1,450–1,460
Fine white sandstone	1,460–1,480
Black and white sandstone	1,480–1,500
Brown sandstone	1,500–1,560
Dark-red sandstone	1,560–1,600
Light-brown sandstone	1,600–1,660
Gray sandstone	1,660–1,690
Brown sandstone	1,690–1,705
Black and white sandstone	1,705–1,965
Dark-gray sandstone	1,965–2,000
Gray sandstone	2,000–2,100
Gray shale	2,100

Main water supply at 632 feet. Water rose to within 70 feet of mouth of well.

129. Well on northwest corner of Vanderventer and Forrest Park Boulevard, St. Louis, Mo.

[Begun October 26, completed December 7, 1904. Authority, E. D. Meloy, driller.]

	Feet.
Filled ground	0– 20
Soft gray clay	20– 40
Sand and gravel	40– 60
Hard gray limestone (shaly); a little water	60– 80
Soft brown limestone	80–100
Hard brown limestone	100–120
Soft gray limestone; water 140–160 and 185–210	120–240
Soft gray shale	240–260
Hard gray limestone	260–265
Soft gray limestone and shale	265–280
Gray limestone; showing of oil 280–290 and 305–325	280–460
Very hard gray limestone and chert	460–470
Hard gray limestone	470–485
Soft gray shale	485–490

	Feet.
Hard gray limestone	490–510
Soft dark-red shale; showing of oil	510–530
Hard gray limestone	530–565
Hard gray limestone and shale; bad caves	565–600
Soft black shale; a little oil	600–620
Soft brown limestone, Trenton; a little oil	620–650

"From 490 to 600 feet is probably Kinderhook, from 600 to 620 feet is probably Devonian Ohio shale."—E. O. Ulrich.

Well yields a small amount of gas.

141. Well 1½ miles northeast of Pleasantville, Atlantic County, N. J.

[Begun January 27, 1903, completed January 31, 1903. Authority, E. E. Lanpher, assistant civil engineer, Atlantic City water department.]

Elevation of mouth of well, 10 feet A. T.	Feet.
Yellow sand and gravel	0– 18
Gravel mixed with clay	18– 23
Soft blue clay	23– 29
Yellow sand and wood	29– 35
White sand; water-bearing	35– 55
Yellow sand and gravel; water-bearing	55–100
Hard light-gray clay and gravel	100–120
Soft gray sand and clay	120–138
Red and white sand; water flowed over casing 2 feet above ground	138–158
Coarse and fine gray sand	158–230
Soft gray sand and clay	230–240
Coarse gray sand	240–250
Soft greenish-gray marl and sand, growing harder toward bottom of bed	250–310
Hard gray clay	310–320

Well discontinued at 320 feet in a rather soft gray sandy clay, and casing withdrawn. Rig used, jet. This was a 4½-inch test well at the Absecon Pumping Station of the water department of Atlantic City. The location is the same as that of the United States Meteorological Station, Pleasantville, N. J. The well was never pumped. Within one-fourth mile of this test well are eleven 10-inch and one 4½-inch wells, yielding about 4,000,000 gallons a day and sunk to about −95 elevation, and one 18-inch well yielding about 700,000 gallons a day, sunk to about −190 elevation. All these wells belong to the water department of Atlantic City and are pumped by compressed air.

157. Well one-half mile west of Atlantic Highlands, Monmouth County, N. J.

[Begun October 1, 1904, completed November 1, 1904. Authority, F. E. Price, superintendent, Atlantic Highlands Waterworks.]

	Feet.
Red sand and clay	0– 8
Bluish sand and marl	8– 16
Gray sand	16– 30
Yellowish sand and wood	30– 40
Light-gray sand; wood between 137 and 157 feet	40–157
Marl (dark gray)	157–244
Marl (fine gray micaceous sand)	244–272
Dark-gray sand	272–292
Marl (dark gray)	292–346

	Feet.
Sand and clay (white and greenish)	346–365
Sandy clay (fine light-gray micaceous sand)	365–392
Gray sand	392–452

Rig used, jet. Diameter of well, 4½ inches. Length of casing, 412 feet. Strainer inserted at 412 feet. Well flows 20 gallons a minute and yields 125 gallons by pumping.

174. Well No. 1, Group B, Solway Process Company, Tully, Onondaga County, N. Y.

[Produced brine October 30, 1890. Authority, Solway Process Company.]

	Feet.
Elevation of floor line, 509 feet A. T. (Syracuse datum.)	
Drift	0– 12
Hamilton:	
Soft gray shale	12– 192
Blue shale	192– 252
Bluish-gray shale	252– 302
Gray shale	302– 352
Soft gray shale	352– 422
Very soft gray shale	422– 610
Blue shale	610– 680
Onondaga or Corniferous limestone	680– 750
Oriskany sandstone	750– 770
Salina or Lower Helderberg?:	
Blue-black magnesian limestone	770– 795
Gray gypseous limestone	795– 885
Blue-black limestone	885– 895
Salina:	
Gray magnesian limestone	895–1,025
Gray gypseous shale	1,025–1,090
Greenish limestone	1,090–1,135
Black gypseous shale	1,135–1,175
Salt	1,175–1,493
Shale at 1,493.	

201. Well in South Lima district, Findlay, Hancock County, Ohio.

[Begun October 10, 1904, completed October 23, 1904. Authority, J. E. Finnerty.]

	Feet.
Surface soil	0– 25
Hard gray limestone; good drinking water between 34 and 50 feet, and black sulphurous water between 50 and 60 feet	25–165
Dark-blue shale	165–170
Dark-blue limestone	170–175
Hard gray limestone	175–180
Soft gray shale	180–185
Hard light-gray and brown limestone	185–235
Hard dark-gray shale	235–245
Hard light-brown limestone	245–260
Soft light-blue shale	260–310
Soft red shale	310–355
Soft blue shale	355–540
Hard blue limestone	540–560
Hard blue shale	560–600
Soft blue shale	600–950

	Feet.
Soft brown shale	950–1,040
Soft black shale—harder last 15 feet	1,040–1,115
Trenton limestone	1,115–1,158

Twenty-five feet 8¼-inch drive pipe. Diameter of well, 6¼ inches from 25 to 1,158 feet. Length of casing, 310 feet to top of red Medina shale. After casing was seated and found tight, drillers made from 115 to 130 feet a tour, and no water was found until well was finished and shot with 100 quarts of glycerine. After the shot there was more salt water than could be pumped, so the well was plugged and casing pulled. Well was drilled for gas. Small amount obtained.

224. Well No. 2 on Mrs. L. Dienst farm, SW. ¼ SW. ¼ sec. 6, T. 4, R. 11 E. (one-fourth mile east of Portage) Wood County, Ohio.

[Begun November 1, completed November 19, 1904. Samples furnished by G. F. Munn, owner.]

	Feet.
Surface soil	0– 20
Gray limestone	20– 200
Blue shale	200– 220
Gray limestone	220– 260
Brownish limestone and pyrite	260– 280
Blue shale	280– 340
Dark red shale	340– 360
Sample missing	360– 380
Blue shale	380– 780
Black shale	780– 920
Brownish gray limestone	920– 940
Reddish shale	940– 960
Gray limestone	960–1,040
Black shale; oil sand at 1,102 feet	1,040–1,120
Brownish-gray limestone with pyrite at 1,180 feet	1,120–1,262

Diameter of well, 8¼ inches from 0 to 300 feet, 6¼ inches from 300 to 1,262 feet. Length of casing, 300 feet. Well was shot with 120 quarts of glycerine. Amount of oil obtained, 5 barrels a day. Gas pressure, 50 pounds.

243. Well No. 6 on the L. C. Grimm farm, 1¾ miles northeast of Higbee, Greene County, Pa.

[Begun June 6, completed August 15, 1904. Authority, J. J. Reed, driller.]

	Feet.
Pittsburg coal	920– 927
Big Dunkard sand	1,422–1,517
Gas sand	1,705–1,760
Salt sand	1,770–1,960
Big lime	2,026–2,100
Big Injun sand	2,115–2,345
Thirty-foot sand	2,745–2,805
Fifty-foot sand	2,855–2,910
Gordon sand	2,969–2,994
Shale	2,994–3,005
Fourth sand	3,005–3,076

Yield of oil: 10 barrels.

244. Well No. 1 on the John Lewis farm, Morris Township, Greene County, Pa.

[Begun October 13, completed December 15, 1901. Authority, H. A. Reardon, driller.]

	Feet.
Soft yellow clay	0– 16
Soft black shale	16– 180
Soft white sandstone	180– 195
Soft black shale	195– 300
Hard white limestone	300– 400
Soft black shale	400– 550
Hard white sandstone	550– 575
Soft black shale	575– 600
Hard white sandstone	600– 635
Coal, Waynesburg	635– 640
Hard white limestone	640– 835
Coal, Mapletown	835– 840
Hard white limestone	840– 935
Coal, Pittsburg—cable measurement	935– 945
Hard white limestone	945–1,045
Soft red shale	1,045–1,100
Hard white limestone	1,100–1,200
Soft black shale	1,200–1,335
Hard white sandstone—Little Dunkard sand	1,335–1,350
Soft black shale	1,350–1,450
Hard white sandstone—Big Dunkard sand	1,450–1,510
Soft white shale	1,510, 1,560
Hard white sandstone	1,560–1,585
Soft black shale	1,585–1,685
Soft porous white sandstone—Gas sand	1,685–1,770
Soft black shale	1,770–1,802
Hard white sandstone—Salt sand	1,802–1,910
Soft black shale	1,910–2,080
Hard white limestone—Big lime	2,080–2,135
Hard white sandstone—Big Injun	2,135–2,385
Soft white shale	2,385–2,705
Hard white sandstone—Thirty-foot sand	2,705–2,735
Soft black shale	2,735–2,850
Hard white sandstone—Fifty-foot sand	2,850–2,900
Soft white shale	2,900–2,930
Hard white sandstone—Gordon sand—gas at 2,940	2,930–2,965

Well produces gas. Diameter of casing, 13 inches from 0 to 16 feet, 10 inches from 16 to 200 feet, 8 inches from 200 to 1,590 feet, 6 inches from 1,595 to 2,145 feet.

254. Well No. 11 on the Adams farm in the Grand Valley oil field, 2 miles east of Grand Valley, Eldred Township, Warren County, Pa.

[Begun July 25, completed August 11, 1900. Authority, Josiah G. Winger, contractor.]

	Feet.
Soft yellow subsoil; conductor hole 16 inches in diameter	0– 22
Soft shale and sandstone with little change in the beds; end of 8-inch hole.	22–308
Soft black shale	308–550
Soft light-gray sandstone; Second sand; no showing of oil, no salt water	550–580
Soft blue shale	580–733

	Feet.
Hard reddish-brown sand; Third sand. This stratum overlies the oil stratum	733–740
Hard light-gray sandstone; oil and gas	740–750
Hard white sandstone; salt water in small quantity	750–775
Soft light-gray sandstone; Second pay or Newton sand	775–785
Hard black shale	785–817

This well compares favorably with many others drilled on this good stretch of territory. Thickness of the Third Sand varies from 45 to 60 feet. Wells are producing from 15 to 20 barrels a month that were drilled thirty-three years ago and have been pumped steadily ever since. This lease is known as the "Dunderdale" lease. It includes the Dunderdale farm, Adams, Grandon, and Reno land. A well designated in Carl's Geology as the "Atlas" well was drilled within half a mile of this property in 1865 (1867?). No paying wells have been found near the "Atlas," which produced 15 barrels a day; 1,800 in all.

Diameter of well, 5§ inches from 0 to 308 feet; length of casing, 308 feet.

257. Well No. 2 on the M. Cartwright farm, Newton Pool, 2½ miles northeast of Grand Valley, in Eldred Township, Warren County, Pa.

[Completed September 7, 1894. Authority, Josiah G. Winger, contractor.]

	Feet.
Clay subsoil; conductor hole 16 inches in diameter	0– 12
Shale and sandstone; end of 8-inch hole and end of casing. This section includes first bed of shale, fresh-water sand, second bed of shale, and salt-water sand. The last sand in the 8-inch hole is the Second sand "gravel bed." The gravel bed is 10 feet thick and contains oil and salt water	12–275
Soft black shale; a shell 80 or 90 feet above the Third sand is scarcely perceptible in this field, but farther southwest is 20 feet thick and oil-bearing	275–404
Hard coarse white sandstone; Third sand. This sandstone is flooded with sweet water, which rose 300 feet in the well	404–430
Hard black shale, separating sweet from salt water strata	430–433
Hard pebbly white sandstone; salt water in large quantities	433–447
Medium hard gray pebbly sandstone—"Gas sand"	447–449
Soft light gray, coarse-grained sandstone; pay stratum of the Third Sand	449–462
Hard black shale	462–477.5

In this well the sand is the best yet found. The well is the best producer in the Newton Pool. It produced in the first twenty-four hours and for several succeeding days 65 barrels of oil. The well flowed through the gas pipe and pumped through the tubing. When the well was a year old it was producing 13 barrels a day. It is now (December, 1904) producing 2 barrels a day.

Diameter, 5§ inches from 0 to 275 feet. Length of casing, 275 feet. Initial pressure, 85 pounds.

266. Well No. 2 on the Philadelphia tract, Gilson Pool, 3 miles west of Grand Valley, Eldred Township, Warren County, Pa.

[Completed February, 1891 Authority, Josiah G. Winger, contractor.]

	Feet.
Subsoil; conductor hole 16 inches in diameter	0– 18
Hard sandy shale (limy)	18–100
Soft gray sandstone, water	100–135

	Feet.
Soft black shale	135–150
Hard gray sandstone; first stratum of First sand	150–160
Soft black shale	160–170
Soft gray sandstone; second stratum of First sand; salt water cased off	170–185
Soft blue shale; end of 8-inch hole and end of 5⅝-inch casing	185–200
Soft black shale	200–223
Hard white sandstone, pebbly; Second sand. This 11 feet of sand overlies the oil stratum. It is separated from the lower stratum by a layer of shale 6 inches thick	223–334
Soft white sandstone, pebbly. This 21 feet of oil sand is very coarse, full of pebbles, and easy to drill. Oil, gas, and salt water in this lower stratum of the Second sand	334–355
Black shale; "gravel bed" from 661 to 671 feet	355–375.5

This is the best Second sand pool in this oil field. The sand is very porous. One well of the pool has a record of over 6,000 barrels of oil in its first year. The best wells found in the pool are located on the Theodore Gilson farm, on the Spring Creek and Titusville public road. The pool was developed by Stewart Brothers and later by Tait & Patterson. Yield for the first twenty-four hours, 32 barrels of high-grade oil.

278. Well No. 19, on the Sayers farm, three-fourths mile southeast of Grand Valley, Eldred Township, Warren County, Pa.

[Begun November 14; completed November 22, 1904. Authority, Josiah G. Winger.]

	Feet.
Soft brownish yellow clay	0– 20
Soft brownish yellow quicksand and blue clay	20– 80
Soft blue clay and gravel	80–100
Soft gray sandy clay and gravel	100–120
Hard blue sandstone	120–140
Soft variegated sandstone; 5 feet of First sand at 155 feet	140–180
Hard black shale	180–300
Hard gray sandy shale	300–315
Soft blue shale	315–340
Hard blue shale	340–400
Hard blue sandy shale	400–420
Hard gray shale and sandstone	420–440
Hard gray conglomerate; Third sand; oil in first 10 feet	440–460
Hard white sandstone; salt-water sand	460–485
Gray sandstone; gas sand	485–490
Soft white sandstone; oil sand, the lower stratum of Third sand	490–500
Hard shale	500–520

The quantity of salt water is small, on account of the remarkably fine texture of the salt-water stratum. The sand in a well drilled for the Stanton Oil Company in 1890, only 80 feet distant from this one, was much coarser than this, and the salt water was so plentiful that the company abandoned the well.

Diameter of well, 8 inches from 0 to 310 feet, 8-inch drive pipe from 0 to 140 feet, 6½-inch casing from 140 to 310 feet. Before the 6½-inch casing was placed fresh water rose to within 60 feet of the mouth of the well. Yield of oil the first twenty-four hours, 12 barrels.

279. Well No. 4 on the Smith farm, 2½ miles east of Grand Valley, Eldred Township, Warren County, Pa.

[Begun October 11; completed October 29, 1904. Authority, Josiah G. Winger, contractor.]

	Feet.
Soft yellow subsoil	0– 17
Soft gray shale	17– 60
Gray sandy shale; Mountain sand	60–100
Hard gray sandstone; water sand between 160 and 220 feet	100–220
Soft gray shale	220–235
Hard gray and black sandy shale	235–315
Hard gray, fine-grained sandstone; the "Cap"	315–335
Gray sandstone; oil and gas in small quantities	335–355
Light gray sandstone and shale	355-376
Soft gray and white conglomerate	376–387
Gray sandy shale	387–420
Gray shale	420–460
Soft black shale	460–520
Gray fine sandstone; top of Third sand at 570, but irregular, here represented by a mixture of shale and dark-colored sandstone	520–590
Soft gray sandstone; "Gas sand," inferior quality, no gas found	590–598
Soft light-gray sandstone	598–605
Soft white sandstone; oil sand. One gallon of oil was washed from the sediment from this 5 feet of drillings	605–610
Soft black shale	610–632

The well stood thirty-six hours before it was torpedoed, and had accumulated 5 gallons of oil. Forty-five minutes after torpedo was exploded oil rose in the well to a height of 130 feet. The well produced 12 barrels of good oil the first twenty-four hours.

In this pool the last stratum of the Third sand is pay, and is designated "Newton sand." Farther south the first stratum is oil bearing, and is designated "Grand Valley sand." In a few wells, from 3 to 6 miles south, pay is found in both the upper and lower strata of the Third sand.

Diameter of well, 8 inches from 0 to 235 feet, 5⅝ inches from 235 to 632½ feet. Length of casing, 235 feet.

284. Well No. 25 on the Sturges farm, 4 miles south of Grand Valley, southwest township, Warren County, Pa.

[Begun October 3; completed October 14, 1904. Authority, P. B. McCool, driller.]

	Feet.
Soil; shell at 32 feet	0– 40
Soft shale; soft water at 55 feet; shell 60–80 (sandstone 100–120)	40–240
Hard gray sandstone; Mountain sand	240–280
Gray shale and shells	280–440
Gray sand shells; first oil at 460	440–500
Gray sandstone; First sand	500–545
Soft gray shale, shelly from 620 to 690	545–690
Gray sand shells; Second sand	690–753
Hard gray sandstone; Third sand	753–774
Soft gray shale	774–789

Diameter of well, 8¼ inches from 0 to 285 feet; 5⅝ inches from 285 to 789 feet; length of casing, 285 feet; amount of oil obtained, 5 barrels a day.

285. Well No. 7 on the Speer heirs farm, 1½ miles north of Thomas, Washington County, Pa.

[Begun October 20; completed December 20, 1904. Authority, James Lyle, contractor.]

	Feet.
Soil	0– 20
Hard gray limestone	100– 150
Hard gray limestone, shaly	150– 200
Soft dark-gray shale	200– 250
Soft light-gray shale	250– 330
Pittsburg coal	330– 336
Hard gray limestone	336– 380
Hard gray shale	380– 450
Soft red shale	450– 500
Soft gray shale	500– 550
Soft red shale	550– 600
Soft greenish shale	600– 750
Hard gray sandy shale with some lime	750– 800
Soft blue sandy limestone	800– 850
Hard light-gray sandstone	850– 900
Soft light-gray sandstone	900– 950
Soft dark-gray shale	950–1,000
Dark-gray shale, sandy	1,000–1,082
Coal; fresh water	1,082–1,087
Soft light-gray sandy shale	1,087–1,200
Soft light-gray sandstone	1,200–1,250
Soft white sandstone; gas at 1,285 feet	1,250–1,325
Soft dark-gray shale	1,325–1,400
Hard gray sandstone	1,400–1,500
Hard light-gray sandstone	1,500–1,710
Soft gray shale	1,710–1,930
Hard gray shale	1,930–1,990
Hard gray shaly sandstone	1,990–2,050
Light-gray sandstone	2,050–2,100
Soft light-gray sandy shale	2,100–2,180
Soft light-gray sandstone	2,180–2,243
Blue shale and white sandstone	2,243–2,246
Hard gray sandstone; oil sand; steel-line measurement	2,246–2,252
Soft gray sandstone; pay, oil and a little water	2,252–2,255
Hard white sandstone	2,255–2,275

Diameter of well, 13 inches from 0 to 340 feet, 10 inches from 340 to 696 feet, 8 inches from 696 to 1,547 feet, 6⅝ inches from 1,547 to 2,275 feet. Yield, 15 barrels a day.

301. Well 1¼ miles west of Houston, Harris County, Tex.

[Begun December, 1903; completed February, 1904. Authority, J. Crummy, civil engineer, Houston Water Company.]

	Feet.
Reddish sand	0– 30
Soft gray clay	30– 44
Soft red sand and rock	44– 74
Hard red clay	74– 89
Sand and gravel	89– 93
Hard white clay	93–137
Red sand	137–210

	Feet.
Red clay and gravel; hard drilling	210– 290
Whitish sand and gravel; hard drilling	290– 316
Reddish clay and gravel; hard drilling	316– 356
Red sand; hard drilling	356– 393
White clay and gravel	393– 456
Light-gray sand	456– 496
Clay and gravel	496– 514
Light-gray sand	514– 526
Gravel	526– 532
Whitish clay	532– 570
Very hard rock	570– 571
White sand and gravel	571– 585
Reddish clay	585– 600
Porous rock	600– 602
White clay	602– 608
Sand and gravel	608– 618
Clay	618– 658
White gravel and clay	658– 668
Sand	668– 678
Porous whitish clay and rock	678– 687
White sand	687– 705
Clay and gravel; hard drilling	705– 745
Whitish sand	745– 756
White clay	756– 772
Sand	772– 810
Clay	810– 815
Sand	815– 835
White clay	835– 895
White sand	895– 940
Reddish clay	940–1,134
Hard rock	1,134–1,137
Light-gray sand	1,137–1,179
Clay	1,179–1,236
Whitish sand	1,236–1,314
Hard rock	1,314–1,315
Clay	1,315–1,354
Sand	1,354–1,368
Clay	1,368–1,430
White sand and gravel	1,430–1,470
Hard clay and rock	1,470–1,600
Hard rock; gas	1,600–1,605
Clay	1,605–1,895
Sand	1,895–1,907
Red clay	1,907–2,025

Diameter of well, 8 inches from 0 to 779 feet, 6 inches from 479 to 1,219 feet, and 4 inches from 1,219 to 1,225 feet.

The Houston Water Company has 3 wells in stratum between 137 and 200 feet, 6 between 290 and 316, 5 between 456 and 496, 2 between 571 and 585, 1 between 602 and 618, 5 between 687 and 705, 6 between 772 and 810, 4 between 895 and 940, 4 between 1,137 and 1,139, and 3 between 1,236 and 1,314 feet. All the wells are located within half a mile radius. They have a closed pressure at the surface of from 1 to 18 pounds and flow from 1,000 to 8,000 gallons a day each.

302. Well No. 1 on the L. W. Long farm, Humble (17 miles north of Houston), Harris County, Tex.

[Begun September 17, completed December 22, 1904. Authority, P. M. Cranberry, owner.]

	Feet.
Soft gray sand	30– 40
Hard gray clay	40– 60
Hard bluish sand	60–215
Hard gray sand and clay	215–310
Hard blue sand and clay	310–400
Coarse gray sand	400–470
Fine gray sand	470–495
Hard blue clay	495–508
Hard blue sand and clay mixed	508–572
Hard blue clay	572–645
Hard blue sand and clay in alternate layers	645–710
Hard blue shale	710–950
Mixed rock and sand (limy)	950–990

Marsh gas between 215 and 508 feet. Considerable gas between 645 and 670 feet and a little between 670 and 790 feet. Some oil and much gas between 790 and 950 feet. Oil between 951 and 990 feet. Yield, 100 barrels first twenty-four hours; gravity, 28° Baum.

Diameter of well, 11⅛ inches from 0 to 310 feet, 6 inches from 310 to 950 feet. Strainer inserted at 951 feet.

318. Well No. 1 on the O. Simmons farm, three-fourths mile southwest of forks of Little Sandy, Elk Township, Kanawha County, W. Va.

[Begun September 24, completed November 24, 1904. Authority, J. G. Weller, driller.]

	Feet.
Surface soil	0– 22
Sand (sandy clay or shale)	22– 40
Shale	40– 60
Sandstone; fresh water rose to within 20 feet of surface	60– 70
Soft red shale	70– 76
Soft gray sandstone	76–124
Hard white shale (greenish)	124–155
Light-gray sandstone; fresh water rose to within 10 feet of the surface	155–170
Hard light-gray shale	170–178
Hard light-gray limestone (sandstone)	178–184
Hard light-gray sandstone	184–227
Hard gray shale	227–233
Hard light-gray sandstone	233–300
Hard light-gray shale	300–306
Hard white sandstone	306–318
Black shale, shelly	318–410
Coal	410–412
Black shale, shelly; water cased off at 425 feet	412–452
Hard white sandstone	452–547
Black shale, shelly	547–685
Hard white sandstone	685–730
Black shale, shelly	730–740
Hard white sandstone	740–790
Black shale, shelly	790–857

	Feet.
Hard white sandstone; top of Salt Sand; gas between 928 and 935; estimated yield 500,000 feet in twenty-four hours	857– 935
Soft white sandstone; salt water; steel line measurement	935– 942
Soft white sandstone; hole filled with flowing water	942– 965
Hard white sandstone	965– 990
Hard white sandstone (brown); well stopped flowing	990–1,010
Hard gray and brown sandstone	1,010–1,143
Hard black shale	1,143–1,145
Hard white sandstone	1,145–1,195
Hard dark-gray limestone; Bastard	1,195–1,210
Hard white sandstone	1,210–1,329
Soft white shale (blue)	1,329–1,345
Hard white sandstone; Maxton and Cairo oil sand	1,345–1,365
Hard white sandstone; bottom of Salt sand	1,365–1,402
Black shale, shelly; pencil slate	1,402–1,405
Hard gray limestone, "Big lime"	1,405–1,510
Hard gray limestone; should be Keener sand, was hard and limy	1,510–1,554
Soft gray sandstone, "Big Injun sand"	1,554–1,615
Black shale, shelly	1,615–1,700

The gas in the Salt sand was drowned out by salt water at 1,010 feet. Well dry, casing pulled.

There was no distinction between Keener and Big Injun sands as there should be. Shale brake between Keener and Big Injun sand.

Diameter of casing 10 inches from 0 to 40 feet, 8 inches from 40 to 425 feet, 6⅝ inches from 425 to 1,345 feet.

320. F. D. Hawkins No. 1, Harrisville, Ritchie County, W. Va.

[Authority, W. F. Graham.]

	Feet.
Limestone	190–202
Coal and shale	202–208
Limestone and pyrite	208–220
Gritty limestone	220–250
Red limestone (brown shale)	258–266
Gray limestone	266–274
Gray shale	274–290
Shale, coal and pyrite	290–298
Gray sandstone	298–306
Limestone (sandstone)	306–314
Gray shale	314–322
Limestone (limestone and shale)	322–351
Gray sandstone	351–358
Limestone (sandstone)	358–365
Sandstone	365–384
Red rock, "Little Red"	384–408
Limestone (shale)	408–422
Shale	422–446
Gritty limestone (gray sandstone, limy)	446–467
Shale	467–482
Limestone (shale)	482–489
Shale	489–497
Limestone (sandstone and shale)	497–608
Red rock, "Big Red"	608–664

	Feet.
Sandstone; pyrite	664– 670
Limestone (gray sandy shale, limy)	670– 781
Shale	781– 805
Limestone; pyrite between 813 and 821 (shale between 821 and 852)	805– 852
Shale	852– 867
Limestone (shale)	867– 873
Shale and pyrite	873– 879
Limestone (shale)	879– 885
Shale	885– 892
Limestone (shale)	892– 916
Shale	916– 930
Limestone (shale)	930– 986
Sandstone (red shale)	986– 992
Shale	992–1,006
Limestone (shale)	1,006–1,018
Shale	1,018–1,032
Limestone (shale)	1,032–1,045
Sandstone; Dunkard Sand	1,045–1,155
Shale (coal at 1,219)	1,155–1,219
Sandstone	1,219–1,225
Shale	1,225–1,241
Sandstone; Second Cow Run sand	1,241–1,285
Coal	1,285–1,300
Sandstone	1,300–1,312
Shale	1,312–1,328
Sandstone	1,328–1,340
Shale	1,340–1,348
Limestone (shale)	1,348–1,354
Shale	1,354–1,378
Limestone (shale)	1,378–1,385
Shale; shells from 1,408 to 1,414 feet	1,385–1,438
Sandstone; Gas sand	1,438–1,463
Shale	1,463–1,575
Sandstone; Salt sand	1,575–1,614
Shale	1,614–1,662
Shells; Maxton	1,662–1,669
Limestone	1,669–1,696
Shale; Cairo	1,696–1,699
Limestone, "Big lime;" top of Keener at 1,752 feet, very small showing of gas. Very small showing of light yellow oil between 1,782 and 1,788 feet. Steel line measurements at 1,762 and 1,770 feet	1,699–1,807
Sandstone and shale; brake	1,807–1,813
Sandstone, "Big Injun;" pay, gas and oil, 1,856–1,862 feet. Steel line measurement taken at 1,868 feet	1,813–1,873
Shale	1,873–1,875

Shot with 10 quarts of glycerine and produced 12 barrels flowing.

Dr. George H. Ashley made the following report to Mr. W. F. Graham regarding the geological formations encountered in this well:

"The well appears to have started at about the horizon of the Washington coal. The coal noted at 298 feet is about at the horizon of the Uniontown. The sandstone at 467 feet may be the Sewickley sandstone. The horizon of the Pittsburg coal probably comes at a depth of between 500 and 550 feet. The sandstone between 1,045 and 1,155 feet is probably the Mahoning or 'Cow Run' sandstone.

The coal at 1,219 may be the Lower Freeport or one of the Kittanning coals. The coal at 1,300 may be the Lower Kittanning or Clarion coal. Sandstone and shale from 1,438 to 1,496 is probably Pottsville, including the Salt sand at the horizon assigned by Mr. Graham. The lower part of the section has probably been correctly referred by Mr. Graham, unless it be in the case of the Keener sand, which he has correlated with the Siliceous limestone at 1,752 feet. The existence of a considerable thickness of limestone below would indicate that this occurs in the Big Lime (Greenbrier limestone), and that the Keener occurs in the upper part of the Big Injun immediately below 1,807 feet."

323. Well No. 1 on the J. Murphy farm, 2 miles east of Hundred, Wetzel County, W. Va.

[Begun July 25, completed September 24, 1904. Authority, E. J. Akins, driller.]

	Feet.	
Alluvium	0–	13
Hard limestone	13–	40
Soft shale	40–	60
Limestone and shale; 200 barrels a day of fresh water, slightly sulphurous, caseoff at 115 feet	60–	352
Coal	352–	355
Shale and soft limestone	355–	425
Coarse white sandstone	425–	445
Soft black shale	445–	480
Coarse white sandstone	480–	500
Fairview or Waynesburg coal	500–	505
Coarse white sandstone. These layers of sandstone are soft but wear the bit out of gage	505–	580
Hard limestone; does not wear the bits	580–	640
Harder limestone; breaks heads of bits	640–	740
Coal; Mapletown	740–	745
Hard limestone	745–	750
Shale	750–	790
Hard limestone	790–	825
Soft chalky limestone	825–	844
Coal; Pittsburg	844–	852
Limestone and shale	852–	870
Gritty limestone	870–	890
Lime shells and shale	890–	960
Soft pink rock	960–	980
Red and white cave rock	980–	1,234
Sandstone; Little Dunkard sand	1,234–	1,275
Soft shale	1,275–	1,312
Sandstone; Big Dunkard sand	1,312–	1,348
Shoft shale	1,348–	1,400
Sandstone; Lower Dunkard sand	1,400–	1,475
Coal (black shale)	1,475–	1,480
Sandstone; "Gas" sand	1,480–	1,610
Shale	1,610–	1,650
Sandstone; Salt sand, dry in this well	1,650–	1,890
Shale	1,890–	1,980
Sandstone; Maxton sand, generally called "Little lime." This sand produces paying oil wells of 100 barrels a day within 1 mile of this well. This well yields about 250,000 feet of gas a day from the pay between 1,995 and 2,005 feet	1,980–	2,030
Shale and lime shells	2,030–	2,044

	Feet.
Limestone; Big lime	2,044–2,145
Sandstone; Big Injun sand; some gas between 2,145 and 2,155 feet. The well will yield about 200,000 feet a day from this pay	2,145–2,343
Shale with limestone and sand shells	2,343–2,900
Sandstone; Fifty-foot sand	2,900–2,970
Shale	2,970–2,988
Sandstone; Gordon Stray sand	2,988–3,008
Shale; brake	3,008–3,009
Sandstone; Gordon sand; a little gas, about 50,000 feet a day, between 3,000 and 3,020 feet	3,009–3,040
Shale	3,040–3,055
Sandstone; Fourth sand; this is the sand the well was drilled for. A well flowed 50 barrels an hour 1,000 feet from this well. This one, however, is dry	3,055–3,075
Shale and shells	3,075–3,100
Shale	3,100–3,236.5

The Fourth sand formation and also the Bayard Sand were missing in this well.

Diameter of casing 10 inches from 0 to 115 feet, 8 inches from 115 to 1,234 feet, 6 inches from 1,234 to 2,132 feet.

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Bulletin No. 265

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

GEOLOGY OF THE BOULDER DISTRICT, COLORADO

BY

N. M. FENNEMAN

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

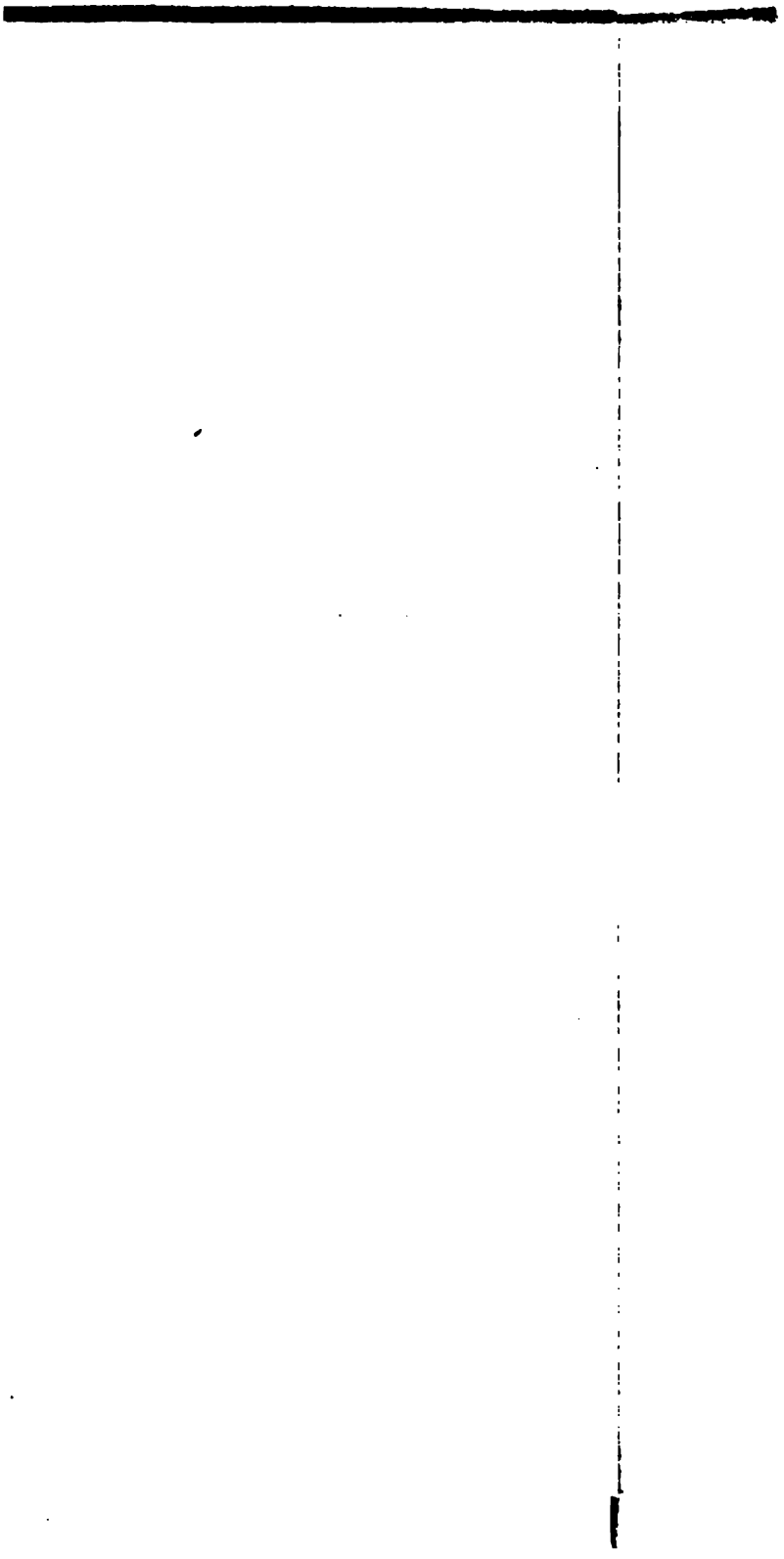
DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., November 18, 1904.

SIR: I transmit herewith the manuscript of a report on the geology of the Boulder district, Colorado, by N. M. Fenneman, and recommend its publication as a bulletin. The report has grown out of a study of the Boulder oil field, begun by Doctor Fenneman in 1902, when this field first came into prominence. Two preliminary reports, giving the more important facts of economic interest bearing on the oil field, together with records of drilling and production, have been published in Bulletins 213 and 225, Contributions to Economic Geology, 1902 and 1903. The present report covers the general geology of the district, its physiography, stratigraphy, and structure, as well as its economic mineral resources, including water, stone, clay, coal, oil, and gas. It is a model discussion of a small but exceptionally interesting district, and will prove of both economic and scientific value.

Very respectfully,

C. W. HAYES,
Geologist in Charge of Geology.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.



GEOLOGY OF THE BOULDER DISTRICT, COLORADO.

By N. M. FENNEMAN.

INTRODUCTION.

The area described in this report is a rectangle 16 miles north and south by 9 miles east and west. The city of Boulder is situated southwest of its center. The immediate occasion of the survey was the finding of petroleum, supposedly in paying quantities. The chief exploitation for oil has been near the center of the area, from 2 to 4 miles northeast of Boulder.

The study was extended southward beyond the village of Marshall, where the structure is more apparent than it is farther north. The northern limit of the area mapped was determined largely by the broad elevation known as "Table Mesa," whose mantle of gravel conceals all the older strata for several miles, and which has not been pierced by the drill. It was found necessary to extend the work to the north side of this mesa, where there are exposures that furnish essential data for the structural problems. The work was carried east far enough to include the excellent exposures of the "White Rocks" at the south end of Gunbarrel Hill; it was extended west beyond the stratified-rock foothills, which contain the chief evidences of the structure.

It was necessary to make a careful study of areas at considerable distances from the oil wells, because the wells are located in the broad central portion of the district on the outcrop of the Pierre shales, which are in general so nonresistant and homogeneous that exposures of solid rock are extremely rare. Here and there in the fields, or on the side of an irrigating ditch, the presence of a thin harder bed may be indicated by a few rock fragments and a sandier soil, but generally the bed is not strong enough to cause even a small ridge, although a little excavation may sometimes reveal its position. Such indications and the inferences from the comparison of not very satisfactory well records are the only direct means by which the structure in the immediate vicinity of the oil wells can be determined.

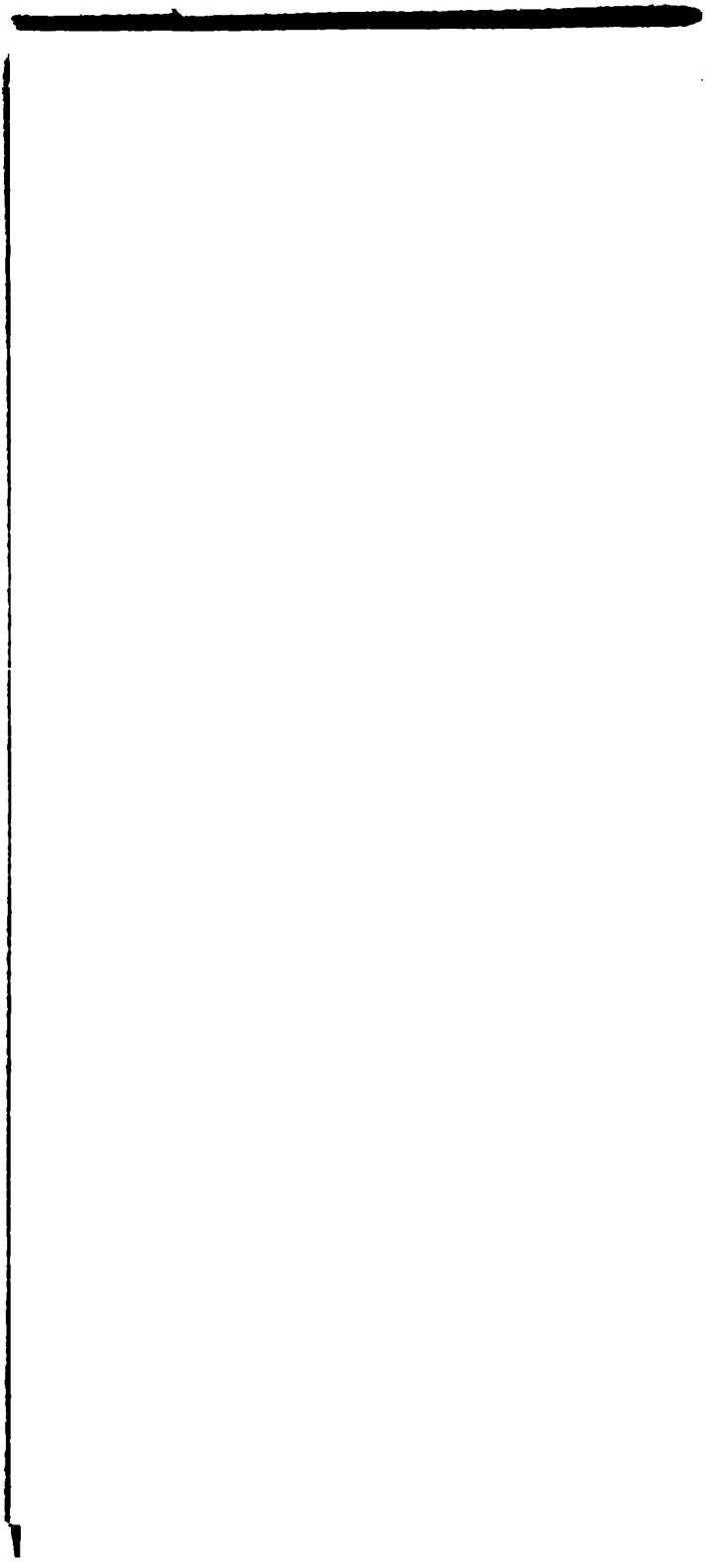
It is otherwise on the borders of the area. On the west are fine exposures of the firm rocks of the foothills. On the south, in the

Marshall coal field, are the eroded folds and scarps of the Laramie sandstone. On the east the Fox Hills and Laramie sandstones offer good exposures. At the north end Haystack Mountain, the only remnant of a terrace higher than Table Mesa, affords an excellent opportunity to study the Pierre shales. At this end of the field even the Pierre contains one or more sandstone strata, which outcrop in definite ridges. The structure of these surrounding districts affords a good basis from which to infer the probable deformations of the strata in the oil territory. It is evident that the structural features so clearly revealed in the foothill belt correspond to those of the oil field. Although the structural features of the shales of the oil field can be made out only by wearisome search, their correlatives in the foothills are open to the light of day. The practical significance of this relation will be evident to any who may be prospecting for similar deposits of oil along the front of the range.

The district here described was studied by the Hayden Survey, and its general features are discussed in the reports of that organization published in 1869 and 1872. The portion of the district south of Fourmile Canyon is included in the Denver basin, which is discussed in Monograph XXVII of the United States Geological Survey by Emmons, Eldridge, and Cross. The southern limit of the area mapped by the Fortieth Parallel Survey is a few miles north of this district, but the description of the major features of the stratigraphy of the east slope of the Front Range as given in the report of that organization is applicable to this field.

ACKNOWLEDGMENTS.

The preparation of the map accompanying this report was made possible by the excellent base map prepared by Mr. Hugh F. Watts, of Boulder, a large part of the geological field work having been done before the publication of the survey atlas sheets. Mr. Watts had also made a geologic map of a part of the region, a generalized reproduction of which is given in this paper as fig. 2 (p. 37). His careful observations were useful at various places, and a few of them are given specific mention in footnotes. Judge Junius Henderson has systematically collected fossils from the district and his cooperation was found valuable. At the present stage of the study, however, it was not deemed advisable to attempt a systematic treatment of fossils. Mr. William R. Rathvon, who has handled for the United Oil Company practically the entire product of the oil field, has generously furnished exact data regarding shipments, and has given much general information concerning the industrial phases of the subject. The plates used are from photographs by Prof. J. R. Brackett. Over half of them were taken expressly for this publication. Prof. R. D.



George, of the University of Colorado, has been consulted on various questions; at the request of the writer he has studied several points in the field, and his conclusions have been received with much confidence. He has read the entire manuscript and his suggestions have been most helpful. The manuscript was subsequently submitted to Mr. George H. Eldridge, a student of oil fields, and one of the authors of the monograph on the Denver basin, who is familiar with much of the area and many of the features here described. Mr. Eldridge's criticisms were found especially pertinent, and on his suggestion certain changes were made.

PHYSIOGRAPHY.

The area may be divided into three north-south strips. A narrow margin on the west belongs to the rough and dissected granite plateau, commonly considered a part of the Front Range of the Rocky Mountains. East of this is the narrow foothill belt, in which a descent of more than 1,000 feet is made to the plains, which form the eastern two-thirds of the area.

TOPOGRAPHY OF THE AREA OF CRYSTALLINE ROCKS.

In a broad sense the name Front Range includes all of the Archean strip west of the Great Plains and the foothill belt. If this part of the range is looked at in more detail, there is seen near the middle of the strip a definite north-south ridge, having its crest about 18 miles west of the upturned strata of the foothills. West of Boulder this ridge reaches an elevation of from 12,000 to 14,000 feet, and has an average slope of from 500 to 1,000 feet in a mile. At approximately the 9,000-foot contour the slope changes. On the west is a relatively abrupt ridge, and on the east a much dissected plateau reaching to the foothills. (See Pl. III, *B*, opposite p. 12.)

The belt between the restricted mountain ridge on the west and the foothills on the east is 10 to 12 miles wide. Its generalized eastward slope is about 250 feet per mile, or from one-fourth to one-half that of the range proper. This strip is cut by narrow valleys to a depth of over 1,000 feet. The interstream areas are generally steep and narrow hills without flat tops, though some ridges continue for several miles with approximately level and unbroken crests. From any high point almost all the summits appear to be in the same plane. The range proper on the west and isolated lumps on the plateau rise with conspicuous abruptness, Sugarloaf Mountain, the top of which is 1,000 feet above the general level, being a prominent example. The topography at once suggests an imperfectly base-leveled surface that has been deeply cut by streams whose erosive power has been increased by recent elevation.

FOOTHILLS.

MONOCLINAL RIDGES.

East of the granite are the red sandstones of the Fountain and Lyons formations, which have an average dip of more than 50° and form a ridge rising 1,000 feet above the plains. The sandstones have apparently resisted weathering better than the crystalline rock, as streams from the west which have cut only narrow canyons through the sandstone ridge generally receive tributaries that flow in north-south valleys in the granite just west of the contact. At places (as at South Boulder Peak) the ridge rises to several times its average height, and towers high above the plateau to the west.

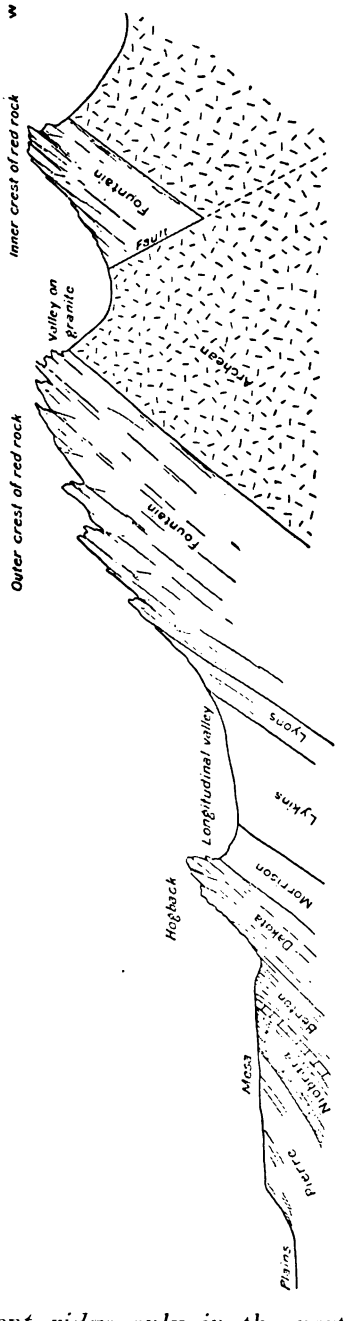


FIG. 1.—Generalized east-west cross section near Boulder. The diagram shows the structure of the South Boulder peaks, of Green Mountain, and of the ridge near Sixmile Canyon.

To these red sandstones, from 500 to 1,500 feet thick, is due a large part of the splendid scenery of this exceptionally fine stretch of foothills. At some places the ridge has an even crest and resembles a wall, while at other places its crags run upward in a long line of spires. (See Pl. III, *A*.) The bare red front of a single crag has sometimes an area of several acres. The outcrop here described may have one, two, or even three distinct crests. They are the westerly members of a series of monoclinal ridges known as "the foothills." Alternations of strong and weak strata, upturned at steep angles, offer the necessary conditions for the carving of these ridges and valleys.

The ridge-making outcrops, taken in order from west to east, are composed of the Fountain, the Dakota, and the Niobrara formations, the last named appearing as a prominent ridge only in the northern part of the area. The order of

A. MESAS AND FOOTHILLS SOUTH OF BOULDER.

B. VIEW WESTWARD FROM GREEN MOUNTAIN.

size is the same as that here given, the height decreasing from west to east.

The Dakota "hogback" is second in prominence to the Fountain crags. It is absent between Sunshine and Pole[a] canyons, but elsewhere it rises steeply to heights of from 100 to 500 feet. The light-gray color of its sandstones is frequently in strong contrast with the red of the rocks farther west. Its crest is commonly covered with pines.

LONGITUDINAL VALLEYS.

Between the red-rock ridge and the Dakota the weaker rocks of the Lykins and Morrison have been cut out in a valley from one-fourth to one-half mile wide. (See fig. 1; also Pl. IV, *A*.) The brilliant color of the former, especially north of Boulder, has given an almost blood-red hue to the soils of the valley. A similar valley, though lacking the color, marks the outcrop of the Benton, where the Niobrara ridge is present. Where the latter forms no ridge, the Benton occupies a long slope from the Dakota hogback to the mesas. This slope is characteristically marked by landslides. At frequent intervals may be seen the typical hummocky topography due to this agency.

MESAS.

East of the last foothill ridges the slope to the plains may be continuous or may be broken by a sharp step, leaving a high terrace adjacent to the foothills. This terrace is called a mesa, or locally "the mesa" (Pl. III, *A*). It occurs in fragments of unequal height abutting against the most easterly foothill ridge or separated from it by a trough due to recent erosion. (Compare Pl. V, *A*, p. 30.) These fragments are commonly separated from one another by ravines. These mesas have a height of from 100 to 300 feet above the lower plains, and a west-east width in this vicinity varying from a fraction of a mile to 3 miles.

SLOPE AND HEIGHT.

The eastward slope of the terraces may be as great as 10° on the foothill side, but it diminishes rapidly toward the plains. At 1 mile east from the foothills a slope of 3° to 4° is common, and at 3 miles the slope is about 1°. An east-west cross section shows an even curve, like the profile of a stream. In addition to the east-

[a] This small gorge in the outer foothills, 2 miles south of Boulder Creek, is locally known as Skunk Canyon. It appears on the maps of the Denver basin as Pole Cat Canyon. For convenience the abbreviated form is here used. The small stream issuing from it is rarely spoken of by any name.

ward slope there is generally a distinct northward or southward inclination toward a lower bench quite similar to the higher, but separated from it by a steep bluff, or more commonly by a ravine. In a general way the highest mesas are farthest from the larger streams, and the height diminishes as these streams are approached.

STRUCTURE AND COVERING.

These mesas are essentially rock benches covered 10 or 20 feet deep with unassorted rock waste. The rocks, chiefly Pierre shales, are steeply upturned, being affected by the mountain uplift. They have been smoothly planed off, not to a flat but to an inclined surface. The débris covering may have a fairly uniform thickness of 20 feet on the highest benches. Generally speaking, the thickness is less in proportion as the mesa surface is lower. This thoroughly unassorted débris comprises fragments of all sizes from sand grains to bowlders more than 10 feet in diameter. The heaviest bowlders are close to the foothills, but fragments a foot or more in diameter are found some miles to the east. On the highest mesas these fragments are almost exclusively from the red rock. The lower benches contain varying proportions of crystalline rock mixed with the débris of red sandstone. The bowlders of the present flood plains are almost exclusively from the crystalline rocks.

ORIGIN.

Some similar mesas farther south have been described as river terraces; others have been ascribed to the cutting of lake shores.[a] It is believed that the mesas in the area here described are remnants of stream terraces,[b] and that the underlying rocks were planed off by the streams that deposited the unassorted débris, just as the present streams are eroding the shales and depositing unassorted material on the new surfaces—that is, on the present flood plains. This conclusion is based on the following facts: (1) The resemblance of the eastward slope of the mesas to the stream profile; (2) the northward or southward inclination of the mesa tops; (3) the variations in the heights of the mesas, the lower in general being nearer the larger streams; (4) the general resemblance of the escarpments to old river bluffs, the higher and lower mesas having the same relationship as higher and lower terraces, except that the mesa remnants are often widely separated by erosion. It is not to be

[a] Emmons, S. F., Geology of the Denver basin: Mon. U. S. Geol. Survey, vol. 27, 1896, p. 9.

[b] Compare Lee, W. T., The origin of the débris-covered mesas of Boulder, Colo.: Jour. Geol., vol. 8, p. 504.

understood that all the mesas are the terraces of existing streams. The general decrease in height as the larger streams are approached might suggest such a relation, but this conclusion is not intended. In the discussion of drainage the location of several former streams concerned in mesa making is indicated.

The hypothesis that these mesas are stream terraces is strengthened by the objections to the hypothesis that they are lake terraces. On the latter assumption, there existed over the adjacent parts of the Great Plains a water body of large but unknown dimensions. The western shore of this lake lay, at first, a few miles east of the present foothill belt. The rocks of this shore were the upturned shales and soft sandstones of the higher Cretaceous series; the original offshore slope was relatively abrupt. Cliff cutting then caused the shore to recede to the present foothill belt. There was left a broad wave-cut terrace, of which the present mesas are remnants, and this marginal terrace was covered with the sheet of débris which now appears as the mesa covering. The facts not readily accounted for on this hypothesis are the following: (1) The absolutely unassorted nature and the frequent angularity of the débris; (2) the entire absence of the outer detrital or built portion of what must in all probability have been a cut-and-built terrace; (3) the difference in the height of terrace remnants abutting against the foothills; (4) the lateral (north or south) slope of the mesas; (5) the dominance of red-rock fragments on the higher mesas and of crystalline rock on the lower terraces, and (6) the lack of well-attested lacustrine deposits over the adjacent plains.[a]

In regard to (1) the fact that the débris is angular and is not assorted, it may be stated that detritus on marginal lake terraces is always assorted, while the thoroughly heterogeneous nature of the mesa gravels agrees to a nicety with that of the deposits of many overloaded streams in arid regions where the small streams are subject to quick alternations of flood and drought. With reference to (2) the absence of the built portion of a cut-and-built terrace, it may be noted that the mesas abut against the mountain front in a kind of embayment, and that a wave-cut terrace in such a situation might be expected to show a lakeward extension of detrital material. The absence of such materials is not believed to be adequately accounted for by subsequent erosion. In fact, a mesa composed entirely of such loose and porous materials as the present surface deposit would, in such a climate as this, be extremely unfavorable to the development of surface streams on account of the ready percola-

[a] Compare Johnson, W. D., The High Plains and their utilization: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1901, p. 653.

tion of surface waters, and would therefore endure longer than a terrace of shales thinly covered by gravels. The significance of (5) the dominance of red-rock fragments on the higher mesas and of crystalline rock on the lower terraces is probably due to the fact that the streams were cutting through red rock when they were at the level of the highest mesas, but as they eroded deeper channels and flowed at lower levels they cut into and carried crystalline rocks. This is further discussed under the heading "Former westward extension of strata." The other objections enumerated above require no discussion.

Wherever the Hygiene sandstone is found it has been planed down to the level of the higher terraces. Upon their surfaces it does not appear, its edge being covered by the mesa gravels. North of Four-mile Canyon, however, wherever the higher terraces have been eroded away the Hygiene sandstone forms a bold ridge whose even crest has the same height as one of the widest terraces. When the sandstone was planed off to its present height this terrace was continuous across the present lowlands.

FORMER WESTWARD EXTENSION OF STRATA.

Whatever streams may have built up any terrace, it is manifest that the oldest mesas are the highest and that the age decreases with diminishing height. Furthermore, the proportion of fragments of red rock to those of crystalline rock decreases as the terraces become lower or as the present flood plains are approached. From these facts it is fair to infer that when the streams were running at the level of the highest mesas they were cutting through red rock for some distance west of the present foothill belt. As a result of the headward elongation of the valleys and of down cutting through the stratified rocks to the granite, the streams carried increasing proportions of crystalline rock, until at present the red rock forms a very small part of the load and hence of the flood-plain débris. As there are no outliers of the red rock on the crystalline area to the west, it is impossible to make any but the roughest estimate of the width of the belt from which the stratified rocks have been denuded.

DRAINAGE.

The district is drained by eastward-flowing streams, which are consequent upon the tilted surface, and is crossed by the two largest creeks—Lefthand and Boulder. South Boulder Creek, of about the same size, unites with Boulder Creek within the area. Most of the

intermediate smaller streams coming from the foothills join these larger creeks within the area mapped.

ADJUSTMENT TO STRUCTURE.

In the almost uniformly strong crystalline rocks to the west all the streams are cutting gorges. There is no progressive adjustment except that which comes from the more rapid widening of the larger valleys at the expense of the smaller. In the almost uniformly weak rocks of the plains all the streams have flood plains, though meandering is but little developed. Here also progressive adjustment to structure is not prominent.

Within the foothill belt the streams from the mountains cross alternately strong and weak strata. Here tributaries are developed in the longitudinal valleys, and at some places adjustment has resulted in stream capture. Across the outcrop of the Dakota and the Fountain the streams flow in steep gorges and corrade their channels with difficulty, while their tributaries in the longitudinal valleys erode the softer strata with ease. As a result, stream capture has taken place, and in the Fountain and Dakota ridges the abandoned channels now appear as small notches analogous to the wind gaps of the Appalachians.

EXAMPLES OF STREAM CAPTURE.

In the Dakota hogback a notch representing a former stream channel appears just north of Bear Canyon. The stream flowing south of east from Green Mountain, and now tributary to the stream in Pole Canyon, lies in a direct line with this notch, and doubtless once crossed the Dakota at this place. At the same time a stream one-third of a mile farther north crossed the Dakota where the ridge was not only much lower and narrower, but was broken by the Pole Canyon transverse fault. In this gap the northern stream lowered its channel rapidly and a vigorous tributary from the south developed on the weak beds west of the Dakota ridge. The development of this tributary gorge was further favored by the eastward slipping of the Dakota ledges. (See p. 48.) The tributary gorge elongated headward until it captured the headwaters of the southern stream and caused its lower course to be abandoned. After this capture and sudden acquisition of more water the valley west of the Dakota ridge was rapidly cut down, and as the support of the steep slope on the west side of the hogback was removed landslipping occurred. (See p. 51.) A similar notch cuts the Dakota

hogback 2 miles farther south and a large one occurs north of Fourmile Gulch. West of the place where Twomile Gulch breaks through the Dakota the ridge of red rock is indented by a notch whose history is similar to that of the notch near Bear Canyon.

The largest stream affected by capture is Lefthand Creek, which approaches the foothills from the west in sec. 26, 6 miles north of Boulder. When this creek reaches the middle of the belt of red rock it turns at right angles and flows north for 1½ miles; it again turns east at Altona, crosses the remaining foothill outcrops, and emerges upon the plains. Almost directly east of its last bend to the north is a sag of more than 100 feet in the Dakota ridge to the east. The drainage channel leading east from this sag, though occupied by a very small stream, pursues an independent course for many miles. It is locally known as Dry Creek, a name applied also to another small stream 5 miles farther south. Along the northern Dry Creek are evidences of a former larger stream—the lower course of Lefthand Creek—which once crossed the foothills in a direct easterly course. Another stream (the present Lefthand Creek) that crossed the foothills at Altona had a course more favorable to down cutting and was able to develop a tributary on its south side, whose headwaters worked far enough south to tap the former Lefthand Creek. The old valley for a short distance east of the "elbow of capture" is now occupied by a small westward-flowing stream which joins Lefthand Creek where it turns to the north.

This recent shifting of the position of Lefthand Creek explains the otherwise anomalous circumstance that Haystack Mountain (Pl. IV, *B*), the highest mesa remnant in the region, lies close to one of the largest streams, which, as already pointed out (p. 14), are near the lowest mesas. The anomalous position of Haystack Mountain is due to the fact that previous to the capture described this mesa was well removed from lines of active erosion.

The terraces to the east offer further interesting evidence concerning the former character of the streams. These terraces are planation surfaces due to meandering and are not base-levels. Some of them are miles in width, indicating that the streams which made them must either have worked a very long time at the same level or have been of considerable size. Knowledge of either one of these conditions, therefore, sheds light upon the other.

As an illustration of the above, much of the surface between Table Mesa and the high mesa 4 miles north of Boulder Creek, a stretch of 3 miles, is at one level, about 150 feet below Table Mesa. The bottoms of the present valleys are from 50 to 75 feet below this lower terrace. Where this terrace has been eroded away by the present

streams the strong Hygiene sandstone stands out as an even-topped ridge, rising to the exact height of this lower terrace. Where the lower terrace has not been eroded the Hygiene sandstone does not appear, having been planed off by meandering streams and covered with the coarse gravel that mantles the mesas and terraces. Small streams now cross the Hygiene sandstone in narrow gorges. All flood plains and low terraces of present streams are narrow in comparison with the broad surface of planation, which has the same height as the top of the sandstone ridge. If the present small streams planed off the broad surface 150 feet below that of Table Mesa, they must have worked longer at one level than would be consistent with the present rate of down cutting.

On the other hand, it is noteworthy that this broad planation surface lies along the course followed by Lefthand Creek before the stream had been shifted northward by the capture described above. This stream was approximately as large as Boulder Creek, and its planation surface is as broad as that of the latter. The supposition that the present small streams meandered at one level long enough to make such a broad planation surface would involve conditions of level or of climate which are not supported by the other evidence.

NATURAL LAKE BASINS.

Scattered over the plains is a considerable number of ponds, some of which have an area of 100 or 200 acres. All of these are used for storage of irrigation waters, and have had their capacities materially enlarged by dams. Some are due entirely to the damming of valleys or "draws," but others are natural basins. Marshall Lake and Boulder (Weisenhorns) Lake are good examples of the latter type. These natural basins are not confined to the surficial sheet of rough gravel, but are often deep in the shales. They originated later than the mesas or terraces which surround them. Some of the small ones might have originated by small landslips or creep, resulting in the damming of small valleys, but most of them can not be thus explained. Boulder Lake has a nearly flat bottom at a depth of approximately 20 feet. The fraction of this depth due to damming, either natural or artificial, is insignificant.

STRATIGRAPHY.

The classification and nomenclature of formations used by Emmons and Eldridge for the Denver basin [a] is in the main followed in this paper. For the area here concerned the succession is as follows:

Quaternary	Alluvium and terrace gravels.
Cretaceous	Laramie.
	Fox Hills.
	Pierre.
	Niobrara.
	Benton.
	Dakota.
Jurassic	Morrison.
Triassic (?) [b]	Lykins.
	Lyons.
	Fountain.
Algonkian	Quartzite of South Boulder Canyon.
Archean	Granites, etc.

ARCHEAN SYSTEM.

The sedimentary rocks of this district rest upon a basement of granite, granite-porphyry, and granite-gneiss, which are at some places gray, but more commonly range from flesh color to red. This basement is cut by frequent dikes; several prominent ones have a north-northwest direction, others trend south of east. These dikes are commonly composed of pegmatite, but there are also several of a light-greenish felsitic porphyry, similar to those which intrude the sedimentaries of the foothills.

The contact of this Archean foundation with the overlying sedimentaries is not a plane, but, in this district at least, the undula-

[a] Mon. U. S. Geol. Survey, vol. 27, 1896.

[b] The writer is indebted to Mr. George H. Eldridge, one of the authors of the monograph on the Denver basin, for the following note on the group heretofore called Wyoming and tentatively regarded as Triassic:

"Mr. N. H. Darton, of the United States Geological Survey, has had, since the publication of the Denver monograph, especial opportunity to study the sedimentary formations from the Black Hills in South Dakota to the southern portion of the frontal ranges of the Rocky Mountains in New Mexico, and is of the opinion, from evidence accumulated by him, that the "Red Beds" [Fountain] and their overlying "Creamy Sandstone" [Lyons], designated the Lower Wyoming in Monograph 27 of the United States Geological Survey, are Pennsylvanian in age, and that the series known as Upper Wyoming [Lykins] in that monograph is possibly Permian in the lower part and Triassic in the upper.

"The evidence leading to such an inference consists of the presence in the Red Beds, at one or more localities, of limestones containing Pennsylvanian fossils and of the presence of Permian fossils in the Black Hills in what he there correlates with the lower portion of the Upper Wyoming, in the Denver foothill region—that is, with the portion here consisting of the pink shales, fine sandstones, and curly limestones. The higher members of the Upper Wyoming may still be considered Triassic in the absence of evidence to the contrary."

tions are very broad and gentle. The question whether this surface is due to subaerial or to marine deundation is discussed under the heading "Geologic history" (pp. 54–57).

SEDIMENTARY ROCKS.

ALGONKIAN SYSTEM.

QUARTZITE OF SOUTH BOULDER CANYON.

The oldest and lowest sedimentary rock is a quartzite which appears only at the extreme southern end of the area, in South Boulder Canyon. It is regarded as of pre-Cambrian age.[a] It is for the most part white, or stained pink with iron oxide; of medium texture, except at what seems to be the base, where it is a pebble conglomerate. One mile south of the southwest corner of the area mapped the beds are almost vertical and are cut across by the newly constructed grade of the Denver and Northwestern Railroad. The stratum is here 550 feet thick.

This formation does not rest upon the Archean surface at the same angle as the remaining strata. From a point at the base of the Fountain sandstone, which in general rests upon the granite, the quartzite strikes southwest, then for a space nearly west, and then S. 27° W. to far beyond the limits of the area mapped. It dips throughout to the southeast at angles ranging from 60° to 90°. Both north and south of it the same granite complex underlies the Fountain. In its relations to the higher stratified rocks the quartzite is only a part of the complex, on whose nearly plane surface the Fountain is laid down.

The structural relation of this single, steeply upturned stratum, outcropping in a narrow belt for many miles between inclosing granites, is not clear from observations made within this area. So small a part of its entire outcrop is included in this area that the attempt to decide its structural relations will not be made here. Marvine, in his description of the Front Range,[b] regards the granite as a mass of metamorphosed sedimentaries. According to this supposition, the quartzite is merely one of many metamorphosed strata, this one showing plainly its sandstone origin, while its neighbors have become entirely structureless. Van Hise, who has studied the contacts in South Boulder Canyon, believes that the phenomena of contact are those of a sedimentary formation laid down on a granite and gneiss floor.[c] He also thinks it probable that the

[a] Van Hise, C. R., Correlation papers, Archean and Algonkian: Bull. U. S. Geol. Survey No. 86, p. 325.

[b] Seventh Ann. Rept. U. S. Geol. and Geog. Surv. Terr., pp. 83–192.

[c] Van Hise, C. R., Manuscript notes to be used in a revision of pre-Cambrian rocks of North America (Bull. U. S. Geol. Survey No. 86).

quartzite has been folded in, and that the structure is that of an isoclinal syncline.

TRIASSIC (?) SYSTEM.

The rocks in this region, hitherto regarded as of Triassic age and called "Wyoming," embrace three formations—the Fountain, the Lyons, and the Lykins. The term "Red Beds" is popularly used without definite limitations; but the authors of the monograph on the Denver basin have conveniently limited the use of this term to the lowest and largest member of the series. The popular use of the term "red rock" is similarly restricted.

The subdivision into "Lower" and "Upper" Wyoming, adopted for the Denver basin, would also be appropriate to the Boulder area. The lower division, however, clearly embraces two lithological units which it is desired to distinguish in this report. The lower and major part consists chiefly of rather coarse, arkose sandstones and conglomerates of reddish color, while the upper and lesser part is a finer-grained, quartzose sandstone of white, "creamy," or light-reddish color. The coarse red sandstones were called the Fountain formation by Cross in the Pikes Peak folio, a type section being crossed by Fountain Creek, near Manitou. The summit of the Fountain formation is not exposed in the Pikes Peak quadrangle, but Darton[a] has found the character of the Fountain, as described by Cross, to continue to a white sandstone corresponding with the "creamy sandstone" of Eldridge, occurring in the Garden of the Gods, to which the name Lyons sandstone is here given.

FOUNTAIN SANDSTONE.

Lithologic character.—In general the Fountain sandstone is a rough arkose, the individual feldspars often appearing in large crystals. Locally it passes on the one hand into conglomerate and on the other into quartzose sandstone, excellent for building purposes, and even into shale. Micas are frequent, especially in the finer portions.[b] The conglomerate phase may have pebbles of granite and schist or of pure quartz only. The conglomerate of fragments of crystalline rocks is found only at the base, and there not universally. At places it is a beautiful recomposed granite, which at casual glance is not different from a coarse, reddish-brown original granite. Quartz-pebble conglomerate may be found at any or all horizons.

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[a] Bull. Geol. Soc. Am., vol. 15, p. 22.

[b] Prof. R. D. George, of the University of Colorado, has examined many specimens and finds that in large part, at least, this mica may be secondary and may have been derived from the feldspar.

The cement of the mass is silica with an admixture of iron oxides; hence the quartzose beds weather with extreme slowness. Their fragments survive unchanged in the rubble of the mesas, where those of the crystalline rocks can be crushed in the hand.

The color of this rock in its coarser phases is due in part to its pink or red fragments of feldspar. In a large way this is more true of the lower horizons than of the upper, but the same factor is present in nearly all beds to a greater or less degree. In the cement, between the grains, crystals, and fragments, however, red iron oxide also appears, and in a general way affects the coloring in proportion to the fineness of the grain. Where quartz is more abundant the rock sometimes has a lighter color, which locally in loosely aggregated masses may even approach whiteness. Where this is the case it is composed almost entirely of large angular quartz grains that appear to have been assorted out of disintegrated granite, with almost no rounding by wear.

Occasional mottling in freakish forms is apparently caused by leaching of iron oxide by percolating waters. Where the differences in shade are attended by differences in texture, the darker colors occur in the denser portions where the water circulation has been least. In so far as the differential coloring is due to the action of percolating waters, doubtless a concentration of coloring matter in the denser portions has accompanied its leaching from the coarser.

Structure.—The Fountain sandstone is characterized by very thick beds throughout, and cross-bedding may be found at any horizon; at places there is a beautiful flow-and-plunge structure. It is very common to find pebble beds a few inches thick alternating with the finer sediments. Shale is found in distinct streaks or pockets. The thickness of these "Red Beds" is 500 to 600 feet at Boulder Canyon, where they are vertical, and increases both to the north and to the south, approximating 1,500 feet at Fourmile Canyon, where they dip eastward at an angle of 47°. No fossils have been found.

LYONS SANDSTONE.

Character and coloring.—Above these massive beds and more or less arkose sandstones are other beds of purely quartzose sandstone. This upper formation is best developed at Lyons, a few miles north of the area mapped. It is quarried there in large amounts. The formation is named from that locality. The siliceous cement of this sandstone has sufficient iron to produce shades of pink, but the popular name, "creamy sandstones," conveys a wrong impression as to their color. While these beds have a fairly uniform shade they are locally almost white, and at some places red. Where these extremes occur, as at Fourmile Canyon, leaching and concentration of the coloring matter have often produced gaily colored rings and bands.

An extreme phase of this feature is seen in the small red nodules which may even be found loose in their sockets in certain layers[a] and which may involve other causes in addition to those which make simple concretions. Many dendrite figures are found, some of marvelous beauty. They are sometimes obtained in thin flagstones, approximately 2 feet square, the entire side of such a slab being occupied by one symmetrical fern-like figure of exquisite delicacy. No fossils are found.

Cross-bedding.—The long washing and complete assortment which these sands underwent on the shore of the early sea was attended by cross-bedding of unusual dimensions and perfection. The angle of cross-bedding is occasionally as great as 35°. At nearly all of the many quarries opened in this stratum, flags or blocks are taken out along cross-bedding planes. This is not universally true outside the area represented by the map. At some of the Lyons quarries a part of the stone has been taken out along the true bedding, but this is not the rule.

The most striking feature of this cross-bedding, next to its universality and perfection, is its dip. With few exceptions this is at a lower angle than that of the true bedding. If, therefore, the strata were again horizontal the oblique lamination would dip toward the mountains; that is to say, toward the shore that existed at the time the beds were deposited. The significance of this is discussed under the heading "Geologic history."

This cross-bedded stratum reaches a maximum thickness of 297 feet at Fourmile Canyon, and is absent just south of Boulder Creek. It passes by gradations into the Fountain, or "Red Beds," below.

LYKINS FORMATION.

Character and thickness.—Lying conformably upon the rocks just described, which are prevailingly sandstones and strong ridge makers, is a series of sandstones and sandy shales, with a little limestone. This series is the Lykins. The name is taken from Lykins Gulch, at the north end of the area mapped, the scenery along which owes its strange and beautiful character to this formation. It is clearly distinguished from the lower formations by its softness and by its showy colors, the most striking of which is a rich brick red that characterizes its sandy shales and shaly sands. At places the color is more brownish, but it is always deep and rich, and the long foothill valley, always present upon these soft rocks (fig. 1, p. 12; also Pl. IV, *A*, p. 14), is at places brilliantly colored.

The entire series is nowhere shown in a single section because it

[a] Eldridge (Monograph XXVII, p. 54) limits those at Golden to a horizon about 20 feet below the summit.

is easily weathered and consequently thickly covered by waste. At Fourmile Canyon, where the formation is somewhat more than 800 feet thick, the lowest 230 feet are largely, if not wholly, sandstones of a clear red, a little darker than brick. These are overlain by the "crinkled" sandstone (see below), which is here 35 feet thick. Above this for 467 feet there are no exposures, but the soil is very red, and exposures not far distant indicate that most of this thickness is occupied by red arenaceous shales. Above these obscured beds are 100 feet more of the familiar red sandstone. Apparently any horizon of this formation may be slightly calcareous, but this is not general.

The section is essentially the same wherever seen, but the thickness varies greatly. The series is apparently absent just north of Gregory Canyon. If present at all it must have a thickness of only a few feet and is concealed beneath the sheet of waste which obscures almost all the strata between the Fountain and the Niobrara.

As indicated above, for a considerable portion of the column the nature of the rocks is for the most part concealed. At and beyond the north end of the area mapped there are certain slopes on which nearly the entire formation is exposed. Here it does not greatly exceed 300 feet, and, except for the "crinkled" sandstone, the whole exposure is of argillaceous sandstone, brick red in the main, but more brownish near the top. To this, however, must be added at the summit about 20 feet of light-pink or dull-yellowish, thin-bedded sandstone, slightly calcareous. This forms a kind of transition to the well-marked massive gray sandstone, which clearly belongs to the Jurassic.

Eldridge has described the Lykins under the name "Upper Wyoming" at localities farther south, where it contains "clayey strata of bright colors—gray, yellow, green, pink, and lilac."[a] Throughout much of this area there are some hundreds of feet out of the total width of the Lykins belt where beds of such colors could easily be concealed. However, with the exceptions already noted, it is doubtful if anything but ocherous reds reach the north end of the area mapped.

The brownish-red sandstone at or near the top of the series (the dull-yellow, thin-bedded sandstone noted above does not appear everywhere) has a variable thickness. It is more than 100 feet thick at Fourmile Canyon. While primarily a massive sandstone, its exposed ledges weather into shingle-like combs.

"*Crinkled*" *sandstone.*—The persistent band which is here referred to as the "crinkled" sandstone is one of the noticeable features of the series. At places it reveals the presence of the Lykins

[a] Op. cit., p. 56.

where all other beds are covered by the abundant talus of the red rock and Lyons sandstone. This band, nowhere above 35 feet thick, is present wherever the Lykins is found. Its superior hardness causes frequent exposures where the ocherous sandstones above and below it are buried under waste. Such a line of exposures is everywhere found at a nearly uniform distance east of the Lyons sandstone outcrop. It is in the main a sandstone more or less calcareous. Locally it has a bed of dense limestone at its base and sometimes other limestone beds above. Some of these have been quarried for lime. It is of a light-pink or purplish color, clearly and minutely laminated. These laminæ are almost universally deformed, are closely crumpled, and serve to make prominent the effects of a north-south stress which has at places minutely brecciated the rock. The evidences of such a stress are all but lost in the softer massive rocks which are conformable with this layer above and below.

JURASSIC SYSTEM.

MORRISON FORMATION.

Limits.—At the top of the brownish sandstone above mentioned there is an abrupt change to light colors, or at most there may be about 20 feet of beds of intermediate character. The sudden transition is readily seen at many places and is the convenient indication of the division between the Lykins formation and the Morrison, as the overlying Jurassic beds are called. The upper limit of the Morrison is quite as clearly marked by the hard sandstones and conglomerates of the Dakota, but the body of the formation shows considerable variation from place to place. Its maximum thickness may be taken at a little less than 400 feet (as at Bear and Fourmile canyons).

Generalized section.—Sections of the Morrison at various places in this area differ greatly. In the main, however, the formation contains a large proportion of light-colored clays, some moderately indurated and others of flinty hardness, much gray sandstone, often calcareous, and at various horizons beds of highly compact limestone. A very much generalized section would present the beds in about the following order, beginning at the base: Sandstone, clays, limestone, clays. The first and last members of the series are persistent, but the intervening clays and limestone may show two or three alternations and may inclose prominent sandstones.

The thickness of the important sandstone at the base is nowhere less than 10 feet, and may be twice that amount. This bed is persistent and massive, and yields the white building stone commonly known as the "Doctor Bond sandstone." It is slightly calcareous, as are the Morrison sandstones in general. In Bear Canyon it forms the

western one of two strong ridges. This sandstone is everywhere overlain by soft beds which are covered by waste.

The lowest limestone is at places within 15 feet of this basal sandstone. At South Boulder Canyon there are 40 feet of it in one stratum, but at Bear Canyon it is separated into two strata by a massive sandstone. Near Altona there are three distinct limestones, the topmost being a resistant stratum 30 feet thick which may form the crest of the ridge where the Dakota ledge is locally lower. This is the case for a considerable stretch between Fourmile and Sixmile canyons. These limestones are exceedingly compact, and turn brown upon the slightest weathering, though they are normally a dark bluish gray. As the beds are much fractured or affected with incipient fractures, the brown color is so general, even in fragments broken by the hammer, that the normal gray may easily be overlooked. The sandstones above the basal bed are (1) the resistant beds between the limestones and (2) the Saurian sandstone described by Eldridge for the Denver basin.[a]

South of Boulder the intermediate sandstone beds are represented by the eastern one of the two ridges in Bear Canyon. The rock of this ridge differs little from the basal stratum. North of Boulder these beds, whether one or two, have a characteristic purplish hue, an irregular, often closely laminated bedding, a flow-and-plunge structure at places, and a wavy or scaly appearance where split along bedding planes. Where the sandstone shows this phase it may be very hard. Occasionally the crest line of the bold Dakota hogback jogs to the west and follows one of these strong ledges of the Morrison. This occurs at several places south of Altona.

The next 75 or 100 feet are everywhere obscured in this district. The space is doubtless occupied by the "Atlantosaurus clays" described by Eldridge, but their character can only be inferred from exposures farther south beyond this field. Above these softer beds, which do not outcrop, are limestones generally interbedded with clays.

The horizon above the zone of intermittent limestones is marked by a rather persistent sandstone. It is generally calcareous and stained with iron, the coloring usually taking the form of round dots, in general about the size of shot. When so marked it strongly resembles certain strata of the Dakota, but is distinguished from the latter by the fact that it effervesces with acid. The stain is not always distributed in this way, but may give an irregular rusty color to the whole rock. This is the "Saurian sandstone" described by Eldridge, but no animal remains have been found in this field. Its greatest measured thickness here is less than 15 feet.

[a] Eldridge, G. H., Geology of the Denver basin: Mon. U. S. Geol. Survey, vol. 27, 1896, p. 61.

The remaining rocks at the top of the Morrison are dense, hard clays and argillaceous sandstones. They are green, yellow, and purple, and occur in beds that are from a few inches to a few feet thick. The fine-grained indurated rocks are full of fractures and tend to crumble into minute angular fragments. Some beds are calcareous. The thickness of these clays is about 30 feet at South Boulder Canyon and nearly three times that amount at Fourmile. They are well exposed on the south side of Bear Canyon, where they are 75 feet thick.

CRETACEOUS SYSTEM.

DAKOTA FORMATION.

Above the Jurassic comes the prominent Dakota formation, easily recognized and well known in the great hogback which parallels the Front Range for hundreds of miles. It is a firm sandstone that is often quartzitic, is generally thick bedded, and is characterized by frequent cross-bedding and ripple marks. Its more resistant, heavy beds may give to the hogback one, two, or even three constituent ridges or combs.

Basal conglomerate.—At is base, though not everywhere present, is a pebble conglomerate. The constituent pebbles include "abundant limestones, quartzites, clays, flints, jaspers, and rocks of granitic composition, together with the separate mineral constituents of the last."[a] The whole is so firmly cemented that, where unweathered, the rock fractures in broad planes which pass through the pebbles. Frequently a series of thin pebble beds in a mass of sandstone takes the place of the continuous conglomerate. This alternation of beds makes the thickness of the basal zone indefinite, but there are few pebble beds above the first 20 or 30 feet.

Character of the sandstone.—Considerable variation may be discerned in the sandstone, but with the exception of the basal conglomerate no one bed has a constant position in the column. Generally the sandstone is composed of quartz grains, with a siliceous cement, and is gray or yellowish gray. With increase of iron oxide the sandstone exhibits striking features of differential coloring. The most common of these is due to the concentration of the iron into evenly distributed spherical specks, which are of uniform size in a particular bed, but which are as small as small shot in some beds and as large as peas in others. The color of these specks is light brown, but in a weathered crust of such a rock it is often bright red, due, no doubt, to the loss of water from the iron oxide. This dotted coloring is exceedingly common, perhaps more so in the upper portion than in the lower. Frequently, also, the weathered surface of a Dakota

[a] Eldridge, op. cit., p. 63.

block or ledge is blackened by a smooth or even shining crust of manganese and iron oxide.

At intervals between the stronger ridge-making ledges occur layers of thinly laminated shaly sands, aggregating in thickness only a few feet. These crumble out in small angular fragments and their wasting accentuates the relief of the strong ledges. Fire clay is not found in this area. Fragments or impressions of wood are not infrequent, but good fossils were not observed.

Columnar jointing.—Some of the upper beds have a distinct columnar jointing. At Sixmile Canyon certain thin ledges when viewed from a short distance look like sheets of basalt. The bedding faces of these same strata are exposed and resemble a rough pavement of polygonal blocks. This jointing produces irregular columns from 2 to 8 inches in diameter. These beds are not to be confused with the igneous rocks, which are intruded.

The line between the Dakota and the overlying Benton shales, while very distinct in a large way, is not so easily located in detail. Alternations of sandstone and shale occur over a zone of 50 feet or more. The thickness of the Dakota at Bear Canyon is about 320 feet, and at Fourmile Canyon a little greater.

BENTON FORMATION.

Shales and limestone.—The Benton shales have a thickness of more than 500 feet at the north end of the field. They are somewhat thinner at the south end and taper uniformly from both ends toward Boulder Creek, where the formation almost disappears. The great body of the shale is dark. There are frequent layers a few inches thick which are strongly impregnated with iron. The formation is calcareous in varying degree. At many places some beds are composed of a black limestone showing a crystalline surface when broken and having a strong bituminous odor. Six miles north of Boulder several hundred feet of the upper strata have this nature. Elsewhere this phenomenon seems to be confined to isolated beds.

Upper beds and Niobrara contact.—As the summit is approached the blackness disappears and the last 75 feet (observed near the north end of the field) show light-colored limestone, shale, and sandstone. North of Sixmile Canyon these beds, which may be regarded as transitional to the Niobrara, show the following section:

Section of upper part of Benton formation north of Sixmile Canyon.

	Feet.
Greenish sandstone, calcareous in upper third	15
Shales, blue to yellow, noncalcareous	15
Sandstone, noncalcareous, firm, rather purplish	10
Shale, iron stained at intervals	10
Shale, calcareous (or calcareous at top).	

Below these beds is a limestone of variable thickness strongly resembling the basal Niobrara. It occurs in lenses only.

The greenish sandstone at the top is found below the basal Niobrara wherever the latter is exposed in this district. It is generally 10 or 15 feet thick, and is not calcareous except in the upper portion. As it is often very much fractured and the cracks are abundantly filled with carbonate of lime, this calcareous character may be due to infiltration from the limestone above. The blue and yellow shales below are also seen wherever the base of the greenish sandstone is exposed.

NIOBRARA FORMATION.

The Benton is succeeded by the Niobrara, whose prominent characteristic is its calcareous nature. It is composed in small part of true limestones, but the greater mass is made up of calcareous shales, while considerable portions are of intermediate character. Its thickness at Fourmile Canyon is a little more than 400 feet.

The basal stratum of compact limestone rests upon the greenish sandstone which is at the top of the Benton. Occasionally a foot or more of light-colored marl intervenes. Below the Niobrara, as pointed out above, are occasional beds of similar limestone and calcareous shales interbedded with noncalcareous sandstones. In lithological character these transitional beds resemble the Benton more than the Niobrara. The faunal relations are not decisive. It is therefore convenient from a field standpoint to adopt the above-named horizon as the dividing line between the Benton and the Niobrara because of the sharp change at this horizon from a sandstone to a compact limestone.

Basal limestone.—This is generally about 15 feet thick, reaching a probable maximum of 20 feet; it is light gray, dolomitic, and very compact; it breaks with a conchoidal fracture. Its individual beds may be 2 or 3 feet thick and are sometimes separated by thin layers of clay. The bedding is irregular and a 3-foot bed has been seen to pinch out within 10 feet. It abounds in shells of *Inoceramus* and has also some dendritic markings. On its upper side it passes into the calcareous shales through an alternation of thinner limestone and shale beds. These thinner limestone beds are characteristically jointed into small blocks whose edges are rounded, and when exposed in the quarry the bed has the appearance of a pavement.

The basal limestone has been frequently overturned (see p. 50) and has been much crushed by lateral stress. In outcrops it is by far the most prominent stratum between the Dakota and the Laramie, except where the Hygiene sandstone makes its prominent ridge.

Shales.—Most of the Niobrara shales are dark brown, but their outcropping edges weather light gray, sometimes almost white. The top-

A. VIEW NORTHWARD ACROSS MOUTH OF BEAR CANYON.

B. OUTCROPS OF NIOBRARA SHALES.

most beds, which are 10 or 20 feet thick, are of a much lighter brown, and weathering gives to them a characteristic yellow color. These are highly calcareous, and pass at places into impure limestones, 5 or 6 inches thick. This horizon is frequently marked by a ridge. Generally, too, about midway between base and summit, the dark shales which weather white contain harder and more calcareous beds, whose outcrops make low ridges (Pl. V, *B*). Locally these also are impure limestones. In this zone are beds several inches or even a foot thick composed entirely of *Ostrea congesta* shells. More than one of such zones occur at places. As in the basal limestone, the rock has a strongly bituminous odor when struck, especially where fossils are present.

PIERRE FORMATION.

Color.—Above the Niobrara are the Pierre shales, which are more than 5,000 feet thick. They are slate colored, leaden gray, dark brown, and sometimes nearly black. Weathering gives to them a greenish-drab hue, which, at any considerable distance from the foothills, is their color to a depth of 30 feet, more or less. It is therefore the one ordinarily seen. Near the base of the formation, however, just in front of the hogbacks, erosion is more active and the shales are often seen with their original dark colors.

Limestone beds.—While in general noncalcareous, the Pierre has local limy beds. At places these form continuous strata, as, for example, 4 miles north of Boulder, one-half mile east of the contact with the Niobrara. Here, for a thickness of nearly 40 feet, strong limestone beds are so closely grouped as to give the outcrop the appearance of the basal Niobrara. At other places the limestone beds are smaller and more isolated, or are divided into concretionary masses often containing fossils. Less prominent calcareous masses may be found at any horizon either in beds or in more or less perfect concretions.

Concentrations of iron occur in similar but less massive forms, ranging from clear-cut beds to well-formed nodules. The lime and the iron may or may not occur in the same concretionary mass. Many of the calcareous nodules mentioned contain much iron carbonate, which, in progressive oxidation toward the center, gives rise to sharply marked concentric shells differing in color.

Hygiene sandstone member.—Sandy beds may occur at any place in the section. The most prominent and persistent of these is about one-third way up from the base, or a little higher. Its outcrop is chiefly at the north end of the field, where it forms a considerable ridge, though disappearing under Table Mesa. Where it reappears north of this broad mesa its outcrop again forms a strong ridge, which is almost continuous for many miles. The ridge passes

within a mile and a half of the village of Hygiene, where the sandstone is typically developed. The name Hygiene sandstone has therefore been adopted for this member of the Pierre formation. To the public it has become well known on the Culver ranch, 6 miles southwest of Berthoud, where it crosses Little Thompson Creek and where a seepage of oil has long been known. At its outcrop west of Berthoud it has a thickness of several hundred feet. At the north edge of the area described in this report it has a thickness of 250 feet. At Bear Canyon is an isolated outcrop of an equally prominent sandstone, 150 feet thick, which is probably of Hygiene age.

The Hygiene sandstone is thick bedded and frequently cross-bedded. Much of it is dark greenish gray and gritty. The remainder is light gray. The whole is calcareous where fresh. It loses its lime in weathering, takes a paler-greenish tint, and becomes friable. It frequently contains carbonaceous matter resembling small sticks of wood turned to coal. It also contains fossils of invertebrates, but its fauna is not yet known to be distinctive of this horizon.

Near Boulder the Hygiene sandstone is within less than 1,000 feet of the base of the Pierre and is itself a very thin stratum. It thickens greatly toward the north, as do also the shales which lie below it. Five miles north of Boulder the underlying shales, which are 1,000 feet thick near Boulder, have a thickness of about 2,700 feet. Here also the sandstone begins to separate into two strata by the coming in of a shale parting. In the next 2 miles this intercalated shale becomes 200 or 300 feet thick. In so far as the upper sandstone can be identified north of Table Mesa, the indications are that this intervening stratum goes on thickening to the north, in common with other strata.

From these pure sands at one extreme to pure clay shales at the other, the Pierre shows all gradations in composition. The sandy layers are generally firm and gritty, almost as dark colored as the shales themselves, and not very porous. In rare instances light-colored, friable sands are encountered in drilling oil wells.

The thickness of the sandy beds is as variable as their constitution, while the lateral extent of such beds, as indicated by occasional outcrops and by the records of wells, is, in a large majority of cases, a small fraction of a mile. Some of these beds may be lenses, but doubtless the more common mode of lateral limitation of the sands is by a gradual change in composition of the beds into the shales. Such beds are found at irregular depths. As some of them disappear and others come in, their depths vary greatly from place to place.

The upper division of the Hygiene sandstone is characterized by large calcareous concretions several feet in diameter. Where the outcrop appears as a low ridge or only a stony band, these concretions,

crumbling, form isolated rocky patches of angular fragments, frequently showing fossils. The exposures of beds of this description in or near the area described in this report are insufficient for the correlation of their outcrops, or even for the determination of their number. It seems necessary to assume, however, that there is more than one bed, and it is probable that the beds occur at any horizon and are of very limited lateral extent. The upper division of the Hygiene sandstone is here given as a typical case, except that it has far greater continuity than others of its kind. Whatever may be true of these calcareous beds, the sandy beds, except the main stratum described above, are distributed through the column of shales at irregular intervals and are generally of small extent.

FOX HILLS FORMATION.

Within the limits of this area the great body of the Fox Hills is but indefinitely distinguished from the Pierre. In mild contrast with the latter its shales are yellowish instead of slate colored, and are also more arenaceous. This latter quality is plainly shown in the soil produced. At some places the transition zone spoken of by Eldridge[a] as marked by "limestones and small ferruginous nodules" is plainly seen. No attempt has been made to trace on the accompanying map the contact between these two formations, as definite points of contact are infrequent and separation of the areas of the two terranes in a detailed way must in fact rest largely on the character of the soils. This distinction is frequently masked by outwash from the foothills.

The topmost stratum of the Fox Hills is, however, a very definite feature in the stratigraphy. For many feet below it there are occasional sandstone beds, and the intervening shales are highly sandy, but at the top is a continuous bed of sandstone 40 feet thick. It is best exemplified just east of the area mapped, where a fine fault brings it up to view alongside the basal Laramie. The sandstone is here fine grained and yellow, very slightly calcareous, and incloses great calcareous, iron-stained concretions. The entire thickness of the Fox Hills near Niwot is about 1,300 feet.

LARAMIE FORMATION.

The Laramie outcrops in the southeast corner of the area. Within the limits here defined this formation consists essentially of (1) sandstones at the base, (2) sandstones alternating with shales and coal overlying, (3) sandstones above the coal, and (4) clays containing isolated sandstone beds and lignitic streaks.

[a] Mon. U. S. Geol. Survey, vol. 27, p. 71.

Basal sandstones.—The basal sandstones are exposed at various places in the Marshall coal field, but best of all at White Rocks, on the eastern border of the area mapped. Here the bold sandstone escarpment comprises two distinct and massive beds, whose topographic effect, however, is that of a single stratum continuous with the Fox Hills sandstone beneath. The lower Laramie sandstone is 40 feet thick, equaling the underlying Fox Hills sandstone, while between the two are a few feet of thinly laminated sandstones, varying to a lignitic shale. The second and thicker stratum of Laramie is separated from the first by gray, shaly sands, inclosing 10 inches of lignitic shale and above it 10 inches of coal.

Both Laramie beds are clearly distinguished from the Fox Hills by their gray or white color and coarser grain. They are composed of coarse quartz sand, and in addition always show some black specks of an undetermined mineral. The two sandstones differ in the following respects: The upper is distinctly whiter and, where exposed along bedding planes (and to a less degree on fracture planes), the surface is marked by weathered-out cracks, making polygonal patterns a few feet across. Both strata are weakly cemented and noncalcareous, but contain giant concretions which are very calcareous, hard, and, on weathered surfaces, are stained brown with iron oxide.

Beds associated with the coal.—The 75 feet of thinner-bedded sandstones above, containing some shale and coal, are best seen at Marshall. The shales occur at frequent intervals, and are often lignitic. The one workable coal seam is sometimes at the top of this division, but again is overlain by 5 or 10 feet of shales and thin sands; all, however, lie below the more persistent sandstone referred to under (3) above.[a] Aside from the coal seam, no horizon above the basal sandstones is more definite than the *Ostrea glabra* zone, which occurs 15 or 20 feet from the base of the series.

The sandstone above the coal is not unlike the second massive bed above the bottom. It weathers into the same angular patterns, and has the same appearance in the hand specimen. Its thickness is from 8 to 15 feet. The overlying clays, as shown in this area, are yellow and purple, and have frequent lignitic bands but no coal, at least within the limits of the area covered by the map.

QUATERNARY DEPOSITS.

There are no deposits younger than Laramie except the uncompacted mantle rock. This is the coarse mesa gravel (see p. 14), or finer alluvium, similar to the deposit formed by the present streams.

[a] The sandstone "C" of Eldridge, op. cit., p. 74; also p. 346.

In the eastern part of the area, especially in the northeastern corner, are patches of loam which plainly belong to the western margin of the great sheet which covers the surface a little farther east. This is the "loess" of Hayden and Aughey [a] and of Emmons.[b] Just what relation these patches bear to the "Plains marl" of Hay,[c] or the great silt body of the Plains Tertiary,[d] was not determined on account of the narrowness of the area studied.

The whole surface east of the foothills is, in a large way, a patchwork of stream terraces. The oldest surficial deposits are highest and farthest from the larger streams, and there is a decrease in age from those at the top of Haystack Mountain to the recent alluvium. No other time scale is suggested by the phenomena of this portion of the plains than that based on relative altitude and distance from streams. In large part, at least, these deposits are of Pleistocene age, though the time of their beginning is not definitely fixed.

IGNEOUS ROCKS.

The igneous rocks are of interest chiefly with reference to their manner of occurrence and relations to the deformation of the sedimentaries, rather than to their character. Constituent minerals and rock textures are therefore given very brief and summary mention.

ROCKS OF THE ARCHEAN AREA.

The Archean rocks are in general granite and granite-gneiss. The texture is generally coarse and the color very frequently pink on account of the pink orthoclase contained. These rocks are cut by numerous dikes, which are of all sizes up to a maximum of many miles in length and 50 or more feet wide. Their texture is as varied as the dimensions of the dikes. In direction the larger dikes show a tendency to approximate parallelism with the foothill outcrops—that is, with the axis of the foothill monocline. They would, however, if prolonged to the south, meet the foothill belt at a small angle. Their most prominent direction, therefore, is more nearly that of the axes of the échelon folds which branch out from the foothills. This comparison of the general directions of two sets of features of different age is used as a mere convenience in description; it is not intended to affirm a genetic relation.

One of these dikes passes through Orodell, 2 miles west of Boulder. It passes up the valley of Fourmile Creek for a mile north of that

[a] Eighth Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1874, pp. 245–255.

[b] Mon. U. S. Geol. Survey, vol. 27, 1896, p. 261.

[c] Water resources of a portion of the Great Plains; Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 570.

[d] Johnson, W. D., The High Plains and their utilization: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1901, p. 653.

point and goes far to the north-northwest. Its southern end is somewhat interrupted, but its general course is in line with that of the Green Mountain fault (p. 46). The "Hoosier dike," of the same kind, lying 2 miles farther west, is even larger and more continuous.

INTRUSIVES OF THE FOOTHILLS.

In the sedimentaries the intrusion is commonly in the form of sheets. There are also series of apparently disconnected bosses, but these are ranged in lines following the strike of the strata, three or four appearing at about the same horizon within a mile.

There are here no intrusives in the foothills south of Gregory Canyon. Within the narrow limits of the area mapped, at least, such intrusion is limited to the areas of complex folding—that is, it shows a marked association with échelon folding. The greatest sheets occur at the north end, where such folding is shown on the largest scale. In view of the association of certain intrusive rocks with small deformations, the presence of similar rocks beyond the limits of the area here described may well be noted and taken tentatively as a suggestion of the presence of folds. The large importance of these minor folds in the structure of the adjacent oil field gives significance to such associated features. (Compare p. 93.)

SUNSHINE DIKE.

A large dike, 1 mile long and from 15 to 40 feet wide, follows the south side of Sunshine Canyon. A short distance beyond its western end is a similar dike that runs north-northwest parallel to the Orodell pegmatite dike for a mile and then trends northwest in an irregular course to the Orodell dike. The small interruption may be disregarded, and both dikes are here called the Sunshine dike. This dike is crooked and branching, and at places there are two or three parallel dikes, as if the main one were subdivided. The rock of this dike has a dense greenish-gray felsitic groundmass. It contains phenocrysts of quartz, feldspar, and mica, any of which may be one-fourth of an inch in diameter. The proportion of the volume of phenocrysts to that of the groundmass varies greatly. Locally the phenocrysts may constitute half the rock.

FLAGSTAFF SHEET.

On the east side of Flagstaff Hill and near the base of the red rock is an intrusive sheet of the same character as the Sunshine dike. It extends north from Gregory Canyon to within half a mile of Boulder Creek. North of that stream the sheet reappears at the same horizon, and continues a mile to the north. Its greatest width is at least 40 feet. The exact contact on its east side is seen in the Silver

Lake ditch, one-fourth mile north of Boulder Creek. The red rock has here been greatly altered by the heat and both rocks have been much weathered by spring water following the contact.

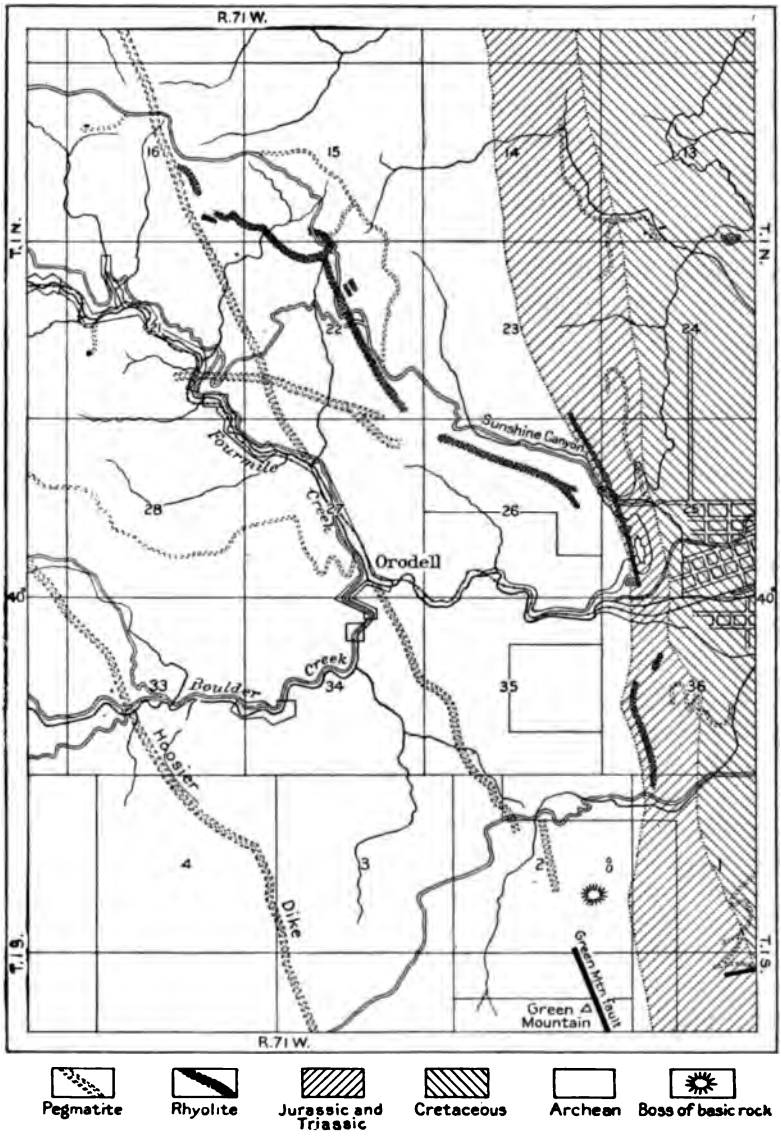

FIG. 2.—Map showing dikes and intrusive sheets west of Boulder. By Hugh F. Watts.

At the north end of Huggins Park is a small offshoot from the main Flagstaff intrusion, or, it may be, merely a dislocated portion of the larger mass involved in the eastward slipping of the red rock. Just below the Huggins Park intrusion is an exposure of the Dakota

sandstones and shaly sands, apparently altered by heat. On this account it is presumable that this small intrusion followed a separate fissure which conducted it to a higher horizon than that of the larger sheet on the west.

PLUMELY CANYON SHEET.

A large sheet of rock similar to that at Flagstaff is intruded in the red rock in Plumely Canyon, a western tributary to Lykins Canyon, at the north end of the area mapped. This is fully 30 feet thick and has thoroughly baked the including strata of arkose sandstone, giving them a black color and a siliceous appearance. Minor beds and pockets of shale in the sandstone have been much more affected by the heat than the latter. Pockets of shale are baked and blackened where the including feldspathic sandstone is unchanged.

ALTONA SHEET.

A larger sheet of the same nature, having at places a width of 100 feet, occurs at or near the base of the Lykins, above the Lyons sandstone and below the ocherous shales. The exposure of this sheet begins at a point west of Altona and extends 2 miles to the north without interruption. For much of its length it forms a prominent ridge on the floor of the large longitudinal valley which has been cut out on the Lykins shales.

South of Altona a 20-foot sheet of the same rock is intrusive near the top of the Lykins. The sandy shales have been greatly altered by heat. Their color has changed from red to black, and some of the shales so strongly resemble lavas that they might be mistaken for such if gradations were not apparent. The contacts of this sheet are far from regular, the magma having run out in small branches, sometimes surrounding blocks of the country rock.

All of these sheets are similar in character to the Sunshine dike described above, though varying greatly in details of texture. All are distinctly porphyritic, though the proportion of phenocrysts to the entire mass is subject to much variation. The very fine-textured groundmass is characteristically green or greenish gray, giving color to the whole rock.

INTRUSIVE ROCKS IN THE DAKOTA AND BENTON.

The Dakota contains intrusives at various places in the northern part of the area. In Sixmile Canyon there are three sheets with an average thickness of 10 feet, and the same rock appears at intervals for 2 miles farther north. It appears in sheets at various places in sec. 25, T. 2 N., R. 71 W. On the north side of sec. 36 of the same township it occurs as a boss which has greatly altered the Dakota

rocks which it intrudes. The intrusives in the Dakota and those in the Benton, which are very similar, differ little, except in color, from those in the older strata. Those in the Dakota and Benton are a dull gray.

A line of bosses occurs near the base of the Benton shales. The most northerly and largest one is in sec. 25. This irregular mass, together with the dike which runs eastward from it, traverses almost the entire width of the Benton strip, which is nearly one-half mile wide at this place. This fissure crosses one of the most prominent of the échelon folds of the foothills. (See fig. 3, p. 44.) The largest boss is centrally located in a group of such folds.

INTRUSIVE ROCKS IN THE NIOBRARA AND PIERRE.

Near the contact of the Niobrara and the Pierre and within a mile north of Boulder is a line of small volcanic knolls. The igneous rock which forms these knolls may be seen at four places. It occurs at the Colorado Sanitarium, near the mouth of Sunshine Canyon, at the base of the Niobrara. At this place it was thrown out from a small excavation and does not cause any topographic feature. One-fourth of a mile to the north it makes a low knoll 500 feet in diameter extending across the Niobrara and into the Pierre. A second and similar knoll occurs 600 feet farther north, this one being entirely within the Pierre. A little north of the middle of sec. 24, T. 1 N., R. 71 W., is another knoll, similar in every way to the other two.

No sheet connecting these four masses has been found, but as they are ranged along the strike of the strata and are all composed of the same rock, they belong undoubtedly to a common magma, which at this horizon became separated along at least four lines of slight resistance. The rock at this highest horizon contains comparatively few crystals. Large masses of it are nearly white, purely felsitic lava.

DIFFERENCES IN FORM OF INTRUSIONS.

From the Fountain sandstone to the shales of the Pierre the sheets become progressively more irregular in continuity and thickness. The thickness of the sheets is almost uniform throughout the Fountain sandstone, but varies in the Lykins. In the Dakota the intrusive sheets have but limited extent and there is a strong tendency for the igneous masses to be concentrated into bosses. In the Benton such localization is the rule. All the intrusives in this formation appear now as isolated knolls, except in the one instance described above, where a dike runs eastward from the largest of such knolls. In the Niobrara and Pierre all igneous rocks appear as completely isolated and well-spaced knolls with no evidence of connecting

sheets. The association of all these igneous rocks with the échelon folds suggests that both the intrusion and the folding occurred during the same process—that is, during the formation of the great foothill monocline.

VALMONT DIKE.

The basic igneous rocks of this area are represented by only one prominent formation—the Valmont dike.[a] This is a great mass of dolerite. Both its occurrence and its petrographic character have been described in detail by Whitman Cross.[b] It has a maximum width of 45 feet and an extreme length of nearly 3 miles, though it is not uninterrupted. From the village of Valmont it extends east by north uninterruptedly 1 mile and as a series of knolls for another mile. For 1 mile west of Valmont it does not appear, but at that distance, in an almost straight line with its course, is a knob of the same rock. The main portion forms a ridge, which rises at Valmont more than 200 feet above Boulder Creek, but which is now being cut away for road material.

This dike is of an even-grained dolerite, divided into large blocks by joints which run parallel and transverse to its length. Within a few inches or a foot of its walls the rock may be divided into thin plates by numerous joints parallel to the bounding surface. In a very narrow zone next to the contact the rock may have a lava-like appearance, but at a distance not greater than a very few inches the characteristic uniform texture of the dike appears.

The stratified rocks containing this dike are (except in case of the isolated knoll to the west) the Fox Hills shales. There is nothing more striking in the whole occurrence than the small degree of alteration which these shales have undergone. Beyond a very little hardening it can not be said that they have been changed at all. In this inference, however, the subsequent weathering is not considered. The vicinity of the contact has doubtless been subject to the work of percolating water. Along the vertical joints of the dike near the contact there have been much weathering and some deposition of calcite.

It is inferred by Cross[c] that this dike "represents a channel through which the basaltic magma rose to the surface;" that this eruption occurred during the Denver epoch; and that strata, since

[a] One-half mile north of Green Mountain there is, surrounded by the granite, a small isolated mass of a peculiar nearly black igneous rock, with large phenocrysts of several kinds. This knob was located and specimens were collected from it by Mr. Hugh F. Watts, to whom the writer is indebted for information and specimen. The rock is unlike any other known within the area.

[b] Bull. U. S. Geol. Survey No. 150, 1898, p. 261; also Geology of the Denver basin: Mon. U. S. Geol. Survey, vol. 27, 1896, pp. 280 and 298.

[c] Bull. cit., p. 261.

denuded, made the surface of the ground about 2,000 feet higher then than now. The nearly complete uniformity of texture from wall to wall is taken to indicate that the magma cooled at a very uniform rate and that the adjacent shales had been thoroughly heated by long-continued passage of lava.

At Burnt Knoll, 3 miles northeast of Marshall, are rocks which bear a remarkable resemblance to lavas. The zone characterized by this appearance is horizontal and confined to the top of the hill, though much of the material has rolled down and now clothes the sides. Apparent injection among fragments of baked shale is the most common phenomenon, but nothing of undoubted volcanic origin has been found. The coal beneath the hill is nowhere affected by heat. Gradations from the most lava-like appearance to ordinary shale indicate that the phenomena are due to heat alone and not to injection. Doubtless the heat came from the burning of associated coal beds, probably ignited by prairie fires.[a]

STRUCTURE.

FOOTHILL MONOCLINE.

The master structural feature of this region is the great upturn of the strata against the mountain range. The form and magnitude of this fold appear most striking when the Archean surface alone is considered. As shown under the heading "Physiography," the first Archean belt west of the foothills is a dissected plateau 10 to 12 miles wide, which slopes east and abuts against the mountain ridge proper on the west. It is from 6,500 to 7,000 feet above sea level at its eastern edge, where it ends abruptly and is flanked by the Fountain sandstone, which has an average dip of about 50°. The height of this sloping face above the plains is nearly 1,000 feet, but this is a small fraction of the true height of the monocline. Five miles east of the base of the foothills the Archean surface is at least 9,500 feet below the surface or 4,200 feet below the level of the sea. The real face of the granite plateau is therefore about 2 miles high, and this enormous rise is accomplished in 6 miles. These figures represent merely the measured thicknesses of strata outcropping in the first 5 miles from the foothills. They do not take into account the possible thinning or thickening within that distance, nor the probable presence of other beds overlapped by those exposed.

The granite plateau on the west shows no evidence of any deformation since its elevation above base-level. The uplift therefore resulted in the formation of an almost simple monocline not less than 2 miles high and 6 miles wide. But it does not follow that this flexing

[a] See also Eldridge, op. cit., p. 75

was brought about entirely by the mountain-making forces. In fact, the greater part of it was apparently accomplished while the thick formations were being deposited to the east and land continued to the west. When the topmost marine stratum, the Fox Hills, was laid down in the shallow water, the elevation of its surface probably differed little from that of the granite terrane to the west. The same statement would be fairly correct for the lowest stratum of the Fountain sandstone during its deposition, and for any intervening bed. While at any time during the long process of sedimentation the last-laid stratum was approximately horizontal and close to the sea level, the originally (nearly) horizontal granite base was getting constantly lower, and its eastward or seaward dip near shore was correspondingly increased.

It follows from the above that before the present Rocky Mountains were formed, and while the area now included in them was close to the sea level, there had been produced a monoclinal fold whose height was but little less than that which would now appear in the granite surface if the sediments were removed. This conclusion involves no hypothetical premise except the generally accepted continuance of land conditions on the site of the Front Range of the Rocky Mountains.

In determining the height of the monocline it must be remembered that the land surface on the west was constantly being lowered by erosion. Occasional or continuous uplift was necessary in order to furnish the material for the sedimentary formations. The amount of flexing is, therefore, the sum of the subsidence of 9,500 feet on the east and an unknown elevation on the west. This rising on the west might even be equal to the sinking on the east, hence the actual height of the flexure is but partially represented by the 2-mile vertical interval between the exposed surface of the Archean west of the foothills and its buried surface under the plains. The total amount of flexing is equal to the offset that would appear if the denudation west of the hinged shore line had not taken place and the sedimentary formations east of that line were removed.

If the above statements are correct the influence of actual mountain making in increasing the height of this monocline was comparatively small. It is, however, conceivable that an east-west compressive force may have accentuated the fold along the steepest part of its slope, thus tending to narrow the belt of dipping strata, while their dip was at the same time steepened. The slope of the monocline previous to the mountain uplift can not be determined unless the shore line is definitely located, which is probably impossible. No reason appears in this area, however, for departing from the common assumption that the sea did not cover the line which is now the axis of the Front Range and which lies a few miles to the west.

It is not conceivable that mere sinking under an increasing load of sediments should have folded the rocks so sharply or along a belt so narrow as the present monocline; yet the height of the flexure is mainly due to that cause. It is only in association with the last and smaller part of the deformation that lateral compressive force is evident. The process of mountain making gave to the granite plateau west of the foothills a comparatively small relative uplift above the plains.

ÉCHELON FOLDS.

Other definite effects of lateral compression are seen in a special type of folding known as "échelon," which at places accompanies the foothill uplift. Such folding indicates that there was a north-south pressure in addition to the dominant east-west pressure. The resultant stress was in lines a little north of east and south of west, causing folds whose axes diverge slightly from the foothill belt, and trend south by east. Within this area such folds are all small. In general, however, such folds are larger in the younger and eastern-most strata. They are largest in the Pierre, become less and less marked to the west, and almost die out by the time the Fountain sandstone is reached. This general rule is not without its exceptions, because the size of such folds is also in a measure dependent on the strength of the strata affected. They are therefore larger and rather more prominent in the weaker Jurassic than in the stronger Dakota above it. Wherever a stratum of some strength is thus folded the end of the canoe-shaped synclinal trough shows a distinct eminence. All the échelon folds are shown on the geologic map (Pl. II).

FOLD NEAR SOUTH BOULDER CANYON.

The échelon fold affecting the lowest strata occurs a mile north of South Boulder Canyon. Here the top of the red rock is offset 1,000 feet to the west on the south side of a small stream as compared with the north side. The younger strata to the east are less and less affected, so that the Dakota is offset but 500 feet and the Niobrara is not folded at all. The location of the fold is significant, being, as it is, at the extremity of the South Boulder fault. The two are but different phases of the same feature and are due to the same act of deformation, only the style of deformation differs.

FOLD SOUTH OF FOURMILE CANYON.

One-half mile south of Fourmile Gulch a mild tendency to this type of folding shows itself in a strong southwest trend of the Dakota hogback, which makes a jog of some 400 feet from its otherwise uniform course. In diminishing degree this fold can be traced

north-northwest and south-southeast to the Jurassic and Benton, respectively.

FOLD IN SEC. 25, 6 MILES NORTH OF BOULDER.

A large number of small, well-developed folds of this kind appear in secs. 36 and 25, 6 miles north of Boulder. In the west half of sec. 25 a prominent, bald, rounded hill rises several hundred feet above the crest of the Dakota ridge, which at this place is broad and less distinctly marked than usual, though not lower. Here, for a short distance, the ridge-making rock is not the Dakota, but the strong, purplish sandstone in the Morrison. The rounded hill mentioned is at the end of a canoe-shaped structural trough in this sandstone. (See fig. 3.) East of it, in the same stratum, is a well-delineated anticline, with an axis pointing south by east, thus diverging slightly from the main trend of the outcrop. The exposed edge of this stratum first runs north, turns around the synclinal hill, loops back to the south for a third of a mile, and then turns north again around the anticline. All the beds of the Jurassic and those adjacent are strongly affected in similar manner. In a direction north by west the fold affects the Fountain sandstone for a number of miles, flattening its eastward dip of nearly 30° to 7° or 8° along the line of the fold. It is largely due to this flattening of dip that the outcrop of the Fountain sandstone is so greatly broadened at the north end of the area mapped. The effect on this formation is also seen in the northeast trend of its eastern boundary, west of Altona.

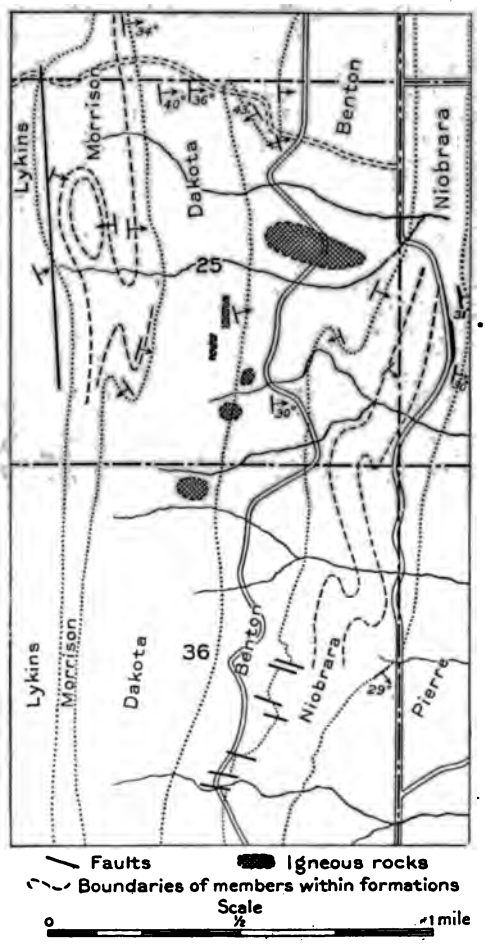

FIG. 3.—Map of secs. 25 and 36, T. 2 N., R. 71 W.

Near the northern line of sec. 25 the upper beds of the Dakota are distorted by an abrupt fold of the same kind. The outcrop, as traced southward, turns backward to the northwest, but in this instance less than a fourth of a mile. The north-northwest continuation of this fold and the fold above mentioned together produce the flattening in the dip of the Fountain sandstone. The southward continuation of this fold is beautifully revealed in the basal limestone of the Niobrara. The higher, shaly limestones of this series are somewhat folded along the same axis, but seem in the main to have slipped one over another at the place where corresponding folds might have been expected. By such means the site of their folding was shifted nearly a mile to the south. The folds show clearly near the east side of sec. 36.

FOLD IN THE HYGIENE SANDSTONE OPPOSITE SIXMILE GULCH.

Just as the north-northwest continuation of this group of folds in secs. 25 and 36 causes a flattening of the dip of the red rock, its continuation in the opposite direction has like effects in the Hygiene sandstone of the Pierre. If the line of the northwestern continuation be extended in the opposite direction, it crosses the Hygiene sandstone in sec. 6, T. 1 N., R. 70 W. At this point the outcrop of the sandstone deviates from its general northerly course and trends straight northeast, making an offset of an entire mile within the section. (See map, Pl. II, p. 10.) This is one expression of the tendency to échelon folding. Another is seen in the reduced dip, 18°, as compared with 55° on the south and 25° on the north. If the line of these folds is extended still farther south, it passes a little west of the producing oil wells. The significance of this in the structure of the oil field is mentioned below (p. 87).

TABLE MESA FOLD.

Two miles north of Altona all strata younger than the red rock strike approximately northeast for several miles, but to the north again following their usual northward trends. In this deformation no such sharply marked échelon folds were developed in the foothill outcrops as are seen farther south. The deformation represented by this incipient fold is, however, large. The effect of the same stress on the Hygiene sandstone was to make a definite anticline whose western limb dips 18° toward the mountains. The sandstone has been eroded from the crest of this fold for fully 3 miles, while it remains in the canoe-shaped syncline west of it. The edge of the Hygiene sandstone is not everywhere exposed, but if laid bare it would make the long loop indicated on the map, west of

Haystack Mountain. (See map, Pl. II. A detailed description is given on p. 88.) The axis of this anticline, if extended southward, would pass a little east of the producing oil wells. Its significance is discussed below.

FAULTS AND LANDSLIPS.

In the foothills of this area there are three large faults and at least one small one whose directions differ little from the strike. The three large ones which affect the western margin of the Fountain outcrop are shown plainly on the map.

SOUTH BOULDER FAULT.

The fault between the two South Boulder peaks strikes south by east from the vicinity of the peaks, but its southerly extension curves more to the east, and it dies out in the incipient échelon fold mentioned above. The downthrow, more than 2,000 feet, is on the west side, repeating the outcrop of the Fountain sandstone and causing two peaks instead of one. (See fig. 1, p. 12.) The two South Boulder peaks will here be spoken of as outer and inner. The outer is made by the main outcrop of the Fountain sandstone. The inner and higher peak is on the fault block of the same formation. It is half a mile southwest of the outer peak.

The fault can be distinctly seen at a point halfway up the valley of the small stream which runs south from the peaks. Here its hade is to the west. As all other features indicate east-west compression in this region, rather than stretching, it is safe to assume that this is a thrust and not a gravity fault. This implies that the hade was toward the upthrow or east side when the strata were faulted, and that it was rotated to its present position by the further tilting of the strata. If made since the strata attained their present position it must be a normal fault, for the present hade is toward the downthrow side. This would indicate stretching, a supposition which is unsupported.

It is difficult to determine how far this fault extends north of the peaks, because its farther extension is in the granite. The block of red rock is not more than 700 feet deep, being limited below by its stratigraphic base, which dips E. 52°, and by the fault plane, which dips west. (See fig. 1, p. 12.) As the gorge leading west from the outer and more northerly peak is much deeper than this, the fault block terminates here and the red rock is not seen farther north.

GREEN MOUNTAIN FAULT.

Another fault, similar in every respect to the one just described, bears the same relation to Green Mountain as the South Boulder

fault does to the inner South Boulder Peak. The Green Mountain fault extends south by east from Green Mountain and dies out in the vicinity of South Boulder Peak. Its extension north of Green Mountain is in the granite and is not apparent. The width of the red rock whose outcrop is thus duplicated west of the main exposure is fully 400 feet; the depth of the block is about the same. The block is terminated by the deep valley just north of Green Mountain. The maximum throw of this fault is probably in Bear Canyon, and is apparently less than that of the South Boulder fault. The granite strip between the duplicated outcrops of the red rock is occupied by streams, as in both the other cases of similar faulting in this area.

FOURMILE FAULT.

A third great strike fault is encountered west of Fourmile Gulch. For 2 miles north of this point it is made evident on the map by the appearance of the red rock in a narrow belt on its west or downthrow side. North of this it extends an unknown distance in the crystalline rock. Its southward continuation runs into the main outcrop of the red rock, south of Fourmile Canyon. The map indicates that at this point a block of red rock is offset to the west. This same block was at first continuous with the isolated fragments to the north, which have subsequently been separated by erosion. The fault has therefore the same general direction and the same relation to the Fountain sandstone as the two faults south of Boulder.

The fault plane itself is not seen, hence the hade is unknown and the depth of the block of sandstone can not be accurately computed. The dip here is but 38°, and the width of the sandstone belt west of the fault is not over 400 feet. If the fault is vertical, the depth of the red-rock block would be but little more than 300 feet. The gorges which cross the fault have cut entirely through the block, and indeed several hundred feet deeper, dividing it into two widely separated parts and isolating both patches from the main outcrop of the Fountain sandstone. Its maximum throw is about 1,100 feet.

FAULT IN SEC. 25, T. 2 N., R. 71 W.

It is significant of the thrust character of these faults that their directions agree with those of the axes of the échelon folds. This relation is emphasized in the case of a small strike fault 6 miles north of Boulder, in the west half of sec. 25. This fault is on the west slope of the prominent bald hill referred to above (p. 44) as formed of a hard Jurassic sandstone and as marking the end of the syncline where the sandstone is characterized by échelon folding. For perhaps half a mile there is a repetition of less than 150 feet

of Jurassic strata. This intimate association of fold and fault at once suggests that the two were caused by the same force; and that each supplemented the other in relieving the east-west stress. This would imply a thrust fault, a supposition which is harmonious with all other observations in the district.

DIP FAULTS IN THE FOOTHILLS.

Dip faults in this area are small. In the next section north of Sixmile Canyon the basal Niobrara shows at least eight dip faults, offsetting the line of outcrop from 10 to 150 feet each—sometimes to the east, sometimes to the west. The belt occupied by the interfault blocks is 300 feet wide. (See fig. 3, p. 44.) The close relation with the folds of the locality leaves little doubt that the two types of deformation are due to the same cause and were produced at the same time. Similar repeated faulting, on a very small scale, also occurs in the Niobrara limestone half a mile south of Gregory Creek. Minute faulting and brecciation at places accompanied the crumpling of the "crinkled" sandstone of the Lykins. It was intense for some distance north and south of Fourmile Gulch.

POLE CANYON SLIP FAULT.

The apparent dip fault in Pole Canyon is the most prominent feature of this nature and is also of great interest. Viewed casually, the feature especially noticeable is a jog of 400 feet in the Dakota ridge, which on the north side of the stream is small, and disappears altogether within a few hundred feet. This jog, which would seem to be sufficient evidence of a fault, does not appear in any formations older than the Jurassic. Of the younger formations, the Benton and Niobrara show no natural exposures on the south side of the stream. On the north side the Dakota, Benton, Niobrara, and Pierre appear in regular succession. In excavations under the end of the Dakota ridge, on the south side, the Niobrara has been encountered in its normal position, unfaulted. The Pierre and Benton are also unbroken; the upturned edges of the Dakota and Jurassic have slipped forward over the unmoved higher strata. There are two fault planes here—a vertical one in an east-west position and a horizontal one which is considerably higher than the present bed of the adjacent stream. This structure must be called a "fault," though its structural value is quite different from that of a fault, as the word is generally used. For want of a specific designation it is here referred to as a "slip fault." It grades into the landslip, but where characteristically represented, as it is here, its true nature must be taken into account in mapping. It is characteristic of such faults

that they are (1) superficial and (2) younger than the upturning of the rocks in the foothills.

HUGGINS PARK.

A feature intermediate between the slip fault and the more ordinary landslip is seen at the middle of sec. 36, at the foot of Flagstaff Hill, west of Boulder. About 300 feet above the plain a bench or terrace a fourth of a mile wide east and west, and of somewhat greater length north and south, is composed of massive beds of the Fountain red rock. Near the front of the bench these rocks are essentially horizontal, but on the west they curve gently upward and become almost vertical. The higher strata from Jurassic to basal Niobrara, inclusive, come up to this bench on the north and on

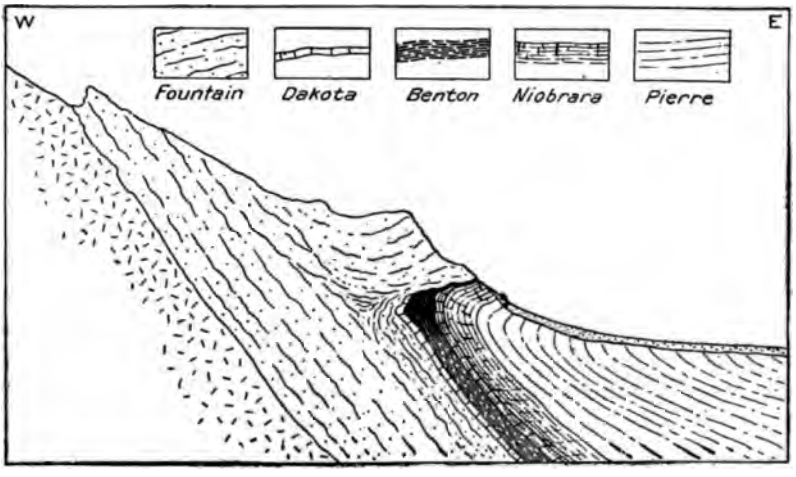

FIG. 4.—Cross section of east slope of Flagstaff Mountain.

the south, and there disappear as if passing beneath the red rock. The bench, known as Huggins Park, is a slide of great dimensions, whose constituent beds are so massive and so unbroken that on the map the red rock is represented as occurring here instead of the higher and younger strata which are covered by the slide. In this case the basal plane, along which slipping has occurred, is in the main a bedding plane, and the phenomenon differs in that respect from the Pole Canyon slip fault.

The recency of this event is shown by a study of the outcrops of the younger strata which were overridden by the red rock in its eastward slipping. The edges of the Dakota, Benton, and Niobrara had been eroded back to a position not differing much from that of the corresponding outcrops which have not been thus covered. When

the slip occurred these outcropping edges were dragged forward and overturned. Under the eastward-facing scarp of Huggins Park one of these overturned beds of the upper Niobrara has been found in an almost horizontal position * (fig. 4, p. 49).

FOOTHILL OVERTURNS.

Just north of Huggins Park the basal Niobrara and its neighbors are overturned in a manner similar to that just described, though not at the present time covered by the red rock. It is fair to assume that at least a part of these beds were overturned by the original movement and their edges dragged eastward. By a careful examination of the contacts of a dike at the north end of the park, also, Prof. R. D. George has shown clearly that there has been vigorous movement along the planes which bound the dike. The relative motion of the dike rock has been forward (east) with reference to its hanging wall (on its west), and backward with reference to its foot wall. The drawing out of the micas into long streaks plainly indicates this.

As similar overturning is common in the Niobrara of this area, and is sometimes alluded to as "fan structure," implying an origin connected with lateral pressure, the significant features of this occurrence north of Huggins Park are here enumerated. They are as follows: (1) The actual overturn is very superficial, its depth being no greater than the height of the ridge due to the strong stratum of the basal Niobrara above the surface of the neighboring shales, 10 to 20 feet in all. (2) With the exception of this narrow crest there is small difference in dip between the nearly vertical red rock on the west and the slightly overturned Niobrara shales on the east of the basal limestone. (3) The overturn of the limestone increases to the south, where the outcrop swings off to the east toward Huggins Park. (4) The overturn is seen half a mile still farther south, under the red rock in the eastward-facing escarpment of the park.

As pointed out above, this feature resembles fan structure, and it should be so described if interpreted as the result of the profounder processes of mountain making. Recourse to these processes is, however, unnecessary to account for any phenomena within the Niobrara of this area; on the contrary, many of the most pronounced examples of overturn, or fan structure, are clearly the result of mere superficial slipping, aided, no doubt, by frost.

Fan structure occurs most frequently in the Niobrara, but the cause lies in the Benton shale west of the Niobrara outcrop. This shale occupies the steep eastward slope of the Dakota hogback, and its surficial parts may be regarded as having a slow eastward move-

* The first recognition of this relation was by Judge Junius Henderson and H. F. Watts. It was first described by Henderson in an article entitled The overturns of the Denver basin: Jour. Geol., vol. 11, 1903, p. 584. Fig. 4, drawn by Watts, is taken from this article.

ment, due to gravity and frost. This movement has involved many landslips, but it has been chiefly effected by creep. The ocular demonstrations of these processes are patches of hummocky landslip topography and superficial overturning of beds. Overturns in the Niobrara may therefore be regarded as due mainly to the eastward creep of its outcropping edges, which were pushed forward by the Benton from the higher slope. In exceptional cases the outcrops have been dragged eastward by landslips.

It is not quite so apparent that the Dakota should have a steeper dip than the Fountain sandstone from causes similar to the ones here defined. It may be shown, however, that the phenomenon is, at some places, a superficial one. The dip of the block affected by slip faulting in Pole Canyon is 20° steeper than the normal dip of the Dakota in that vicinity. Throughout the area the Dakota hogback is in general a high, narrow ridge, rising much higher above the plains on its east side than above the valley on the west. Against the west side, therefore, there is constant pressure of the Morrison and Lykins shales and sands, whose surface has a general eastward slope and thus a tendency to creep eastward, causing pressure against the Dakota ridge. Under these conditions it is difficult to see how the strata of the latter could entirely withstand the tendency to rotation. Where the strata are thickest and the ridge is broadest, and best supported on the east, the dip is least steepened.

An example in the Fountain sandstone further illustrates the shallowness of the zone in which the dips may be affirmed to agree with those at the surface. West of Boulder, and for a short distance north of Sunshine Canyon, the " Red Beds " are vertical. Going north, the dip decreases with comparative abruptness to less than 60°. The strike continues in a uniform direction, and there is no jog in the outcrop. It follows from this that if these diverse surface dips continue to any great depth the Fountain strata are dropped down sharply, and form a deep east-west trough under the city of Boulder—a supposition which is not supported. There has certainly been, since the middle of the Pierre epoch, a great flattening of the Boulder arch, but it is difficult even to conceive of a structural trough in the Fountain sandstone so profound that its dips should be continuous with the present dips of the crags around Sunshine Canyon. It is far more probable that the steep dips of these exposed crags do not continue far beneath the surface.

SLIP OF THE LYKINS IN POLE CANYON.

The direct effect of gravity on foothill topography may be seen at various places along the contact of the Lyons sandstones and the Lykins sandy shales. It is well exemplified in sec. 12, just east of

Green Mountain. (See fig. 5, below.) Here the Lyons sandstone is covered by a long talus slope hundreds of feet high, composed of large blocks derived from the sandstone. The talus slope ends where the Lykins begins. Along this line is a trough, or, more properly, a series of pits, often 20 feet wide and 8 feet deep. Into this irregular trough the lower margin of the talus has fallen. The steeper slope thus made at the foot of the talus has not yet had time to be reduced, and many blocks are in an unstable position. Some have been broken or turned over, and expose fresh surfaces, which contrast with the older weathered or lichen-covered surfaces. Simi-

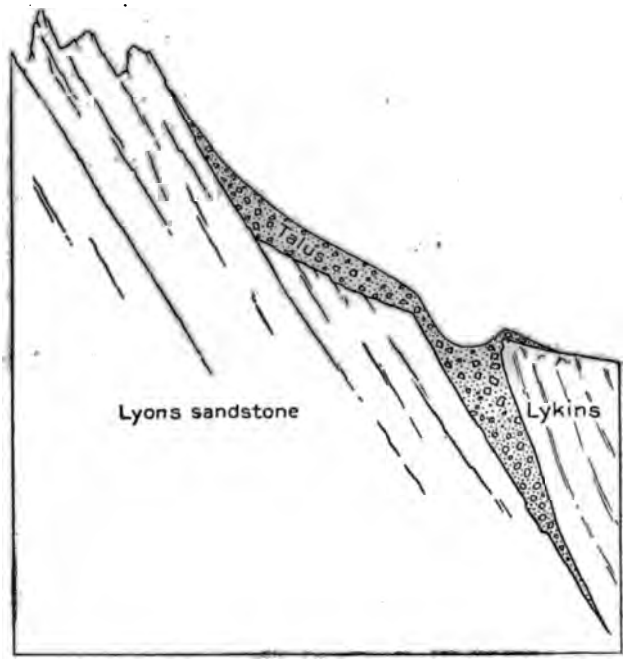

FIG. 5.—Lykins formation in Pole Canyon slipping away from the Lyons sandstone.

lar occurrences are found at various points between Pole and South Boulder canyons.

In explanation of this phenomenon, it is not necessary to assume any other force than gravity. The slope eastward from the contact of the Lyons sandstone and the Lykins is steep and is underlain by shale or sandy shale. At the foot of this steep slope, a fourth of a mile away, a young, deep valley has been cut behind that portion of the Dakota hogback which has been swung forward by slip faulting. (See p. 48.) Similar opportunities for the slipping eastward of the Lykins exist at other points, and are accompanied by the peculiar evidences of slipping described above. The tendency would, of course, be greatly aided by any continuance of the mountain uplift.

FAULTS OF THE PLAINS AREA.

The generally horizontal rocks of the plains are broken by faults much longer than those in the foothills. The throws are, however, very much smaller, rarely exceeding 300 feet. Most of the plains faults within this area converge at Marshall and have their chief interest in connection with coal mining. Any description of them must be little more than a repetition of the excellent account given by Eldridge.[a] They have been traced again in the field and plotted with some detail on the large-scale base map used in this survey. All are far from straight, and their courses are necessarily represented in a generalized way. The actual line of a fault can rarely be seen. Commonly its location is fixed only within several hundred feet by outcropping rocks, whose relations indicate a fault somewhere within the limits named. Fragments of crushed and slickensided rock may define the location more narrowly. In two cases faults can be seen in mines. The faults enumerated in Eldridge's "Marshall subsystem" and two of his "North Boulder faults" are here briefly described under the names given by him.

The main or northern fracture of the Marshall subsystem trends southwest along the northern base of Davidson Mesa to its west end, southwest of which its course is more southerly to beyond the middle of sec. 21, where it is lost. Its northeastern extension also runs in the same direction as its southwest end. It passes half a mile west of Burnt Knoll, northeast along the line of Dry Creek, and is lost. The fault plane, where observed by Eldridge, in a mine now abandoned, dips S. 28° E., at an angle of 45°. As the upthrow is on the southeast side, this is a thrust fault. The maximum throw along its middle course is about 350 feet.

The middle fracture branches off from the main fault near the railroad station at Marshall and follows a northeasterly course, though at its southwestern end the trend is more east than north. Its course is curved similar to that of the northern fault, but the curve is less sharp. The line of the fault crosses the highest part of the mesa near its west end, but farther northeast it follows the foot of the mesa. The fault itself can be seen in a cut of the railroad switch, which encircles the mesa at its western base. The maximum stratigraphic throw of this fault is near its eastern end, and amounts to 180 feet. The downthrow is on the south, so that the fault block on the north has been relatively lifted up between its neighbors.

The southern fracture is approximately parallel to the middle one and distant from it one-fourth to one-third of a mile. It follows a gently sinuous course along the south side of the valley, and south

[a] Mon. U. S. Geol. Survey, vol. 27, 1896, pp. 128–136.

of the Colorado and Southern Railroad, but crosses the valley about the middle of the south side of sec. 15, ascends the mesa to the northeast, and is lost to view in about half a mile. Its southwest end approaches the main or northern fracture near the middle of sec. 21, but here a strong monoclinal fold appears and probably takes the place of the southern fault at its westerly end. The downthrow is on the north and reaches 260 feet. Nearly midway between the middle and southern fractures is another fault of similar direction with downthrow of a few feet on the north.[a]

The block between the middle and southern fractures is cut by the "terminal cross fault," and its west end dropped down about 30 feet. This fault lies a little west of the middle of sec. 15. It trends nearly southeast, but turns more nearly to the south at its southern end, where it seems to cross the southern fracture. It is no doubt the same fault which is encountered in the Gorham mine of the Northern Coal and Coke Company, where the drop on the west side is 10 feet.

The canal fault (so named by Eldridge) is well seen in the deep railroad cut in sec. 13. It runs almost east and west, and has a vertical downthrow on the north of about 50 feet. The massive sandstone on both sides is basal Laramie.

Two of the group of faults appearing on the north side of Boulder Creek lie partly or wholly within the area discussed in this report. No. 1, with upthrow of 180 feet on the east side, brings up the Fox Hills shale in the east halves of secs. 12 and 13 at the eastern edge of the area mapped. The opposing stratum on the west is basal Laramie. No. 2 has 60 feet of upthrow on the east, the opposing strata being Laramie on both sides. All trace of these faults is lost under the alluvium of the valley on the south and also under the surface of Gunbarrel Hill on the north.

GEOLOGIC HISTORY.

PRE-FOUNTAIN TOPOGRAPHY.

The geologic history of the Fountain sandstone is considered with especial reference to the topography of the preexisting land surface. The uneven contact between the Archean and Fountain rocks is understood to represent the subaerial topography of Fountain time as modified by shore erosion during gradual submergence beneath the sea. The principles by which the character of the early topography and of the marine denudation is inferred from the present features can not here be discussed in detail.[b] The observations

[a] The writer's attention was called to this small fault by Mr. H. F. Watts.

[b] See the writer, Effect of cliff erosion on form of contact surfaces: Bull. Geol. Soc. Am., vol. 16, pp. 205–214.

given below, however, point to the conclusion that during submergence the form of the old land surface was much changed by wave erosion.

The Archean-Fountain contact differs from a plane only when broad areas are considered. The undulations of the contact line shown on the map give an exaggerated idea of the unevenness of the Archean surface, but, ignoring the effects of faults, most of the deviations from straightness are due to the irregularities of the present surface.

In the main the proof of the inequalities of the Archean floor is the varying thickness of the red rock. A casual look at the map may be somewhat misleading as to the amount of such variation, for at Boulder, where the band is narrowest, the beds are vertical; toward the north the dip decreases, and where the outcrop is very wide, the dip is but from 7° to 30°. The thickness of the Lyons-Fountain sandstones varies from 500 feet at Boulder to possibly 1,500 feet at Fourmile Canyon and at Bear Canyon, 3 miles south of Boulder. At Lefthand Creek, 3 miles north of Fourmile Canyon, it does not exceed 1,000 feet.

If the eastward tilting due to mountain-making forces were undone and the red rock removed, the exposed Archean surface would show only very smooth, broad undulations. In this area the slopes would not be less than 3 miles long, would have a grade, except at one place, not exceeding 150 feet to the mile, and would be entirely unbroken by valleys. The one exceptional feature of the relief would be a hill, or east-west ridge, at Boulder, rising possibly 1,000 feet above the valleys north and south of it, but having a base 6 miles wide and perfectly smooth slopes. This hill or ridge, however, marks a well-known line of weakness, along which there has been frequent uplifting; it does not, therefore, represent the relief of the floor upon which the Fountain sandstone was laid; it was more probably being elevated during the deposition of the latter, or, rather, it was subsiding less rapidly than the areas north and south. (Compare p. 64.)

The Archean rocks below the Fountain are unweathered. Those which are in immediate contact with the red rock do not differ in this respect from those which occur at a greater distance back in the mountains. In like manner, the felspathic constituents of the stratified rocks are essentially unchanged. The sediments also contain many unweathered rock fragments. The material composing much of the red rock is not unlike the disintegrated granite which now covers many of the steepest hillsides, with this exception, that it has been to some small extent transported by water. Nevertheless, these sediments are in the main but little waterworn and poorly assorted. They are such as should be found near a land which is being actively

eroded by streams as well as by waves—that is, where erosion is relatively active as compared with weathering; the more arid the climate the less active need erosion be in order to yield such waste. Such sediments belong to a shore where trituration is not prolonged, and where the bottom subsides so rapidly that the particles are carried downward into quiet water before they have been rounded or broken up.

The above features of form and material suggest that the configuration of the present contact is the result of a considerable change in the topography of the old land. The absence of smaller irregularities on the broad swells that slope 150 feet to the mile and an unweathered rock bed would not both characterize an area subjected to subaerial erosion. If the former land surface was a peneplain its deeply weathered surface could not have supplied the large proportion of feldspar fragments in the red rock, and its slowly flowing streams could not have transported them from the higher land on the west. On the other hand if the surface had its present relief its long slopes would have been cut into sharp hills and valleys. The invading sea, therefore, must have shaved from the surface enough material to obliterate all the relief except the major features, which have been left in a very generalized form.

SHORE EROSION DURING SUBSIDENCE.

The form of the shore line of an advancing sea is indicative of the form of the sea bottom near the shore. This is apparent from the fact that the shore line at any stage of subsidence is the highest contour of the sea bottom and is similar to the other contours, each of which was, in its turn, the shore line. When the submerged surface, therefore, is a plane, whose contour lines are straight, the shifting shore line is known to have been without bays. When the sea bottom is undulating, the shore line of the advancing sea was characterized by bays and headlands.

During the invasion of the Fountain sea, therefore, the shore line was not straight (since the surface of denudation is not a plane), but there has been found no trace of bay heads where filling was in progress. The universal freshness of the underlying granite is evidence that cliff cutting occurred everywhere. The bays that existed did not extend so far inland as to preclude erosion at their heads. While this universal cliff cutting was taking place the surface rocks were being removed from both hills and valleys, though the erosion was greater on the hills than in the valleys. Between headlands 6 or 8 miles apart the water would have been possibly 500 feet deep. These dimensions, which follow from measurements given above, are perfectly consistent with the assumption that the bays were so wide open as to allow wave erosion at their very heads.

The supposition is a long way within the possibilities of shore erosion.

From the above-stated relation of the shore line to the contours of a submerged surface it follows that if a retreating shore line is a sinuous cliff the sea bottom will have a fluted surface. There will be ridges along the lines of retreat of the headlands and furrows where the bay heads receded. If there is suitable offshore slope and rate of subsidence, even the coarse waste may be laid down in beds, which are continuous over these ridges, instead of abutting against them. All these conditions occur along the lower contact of the Fountain sandstone. Fine flow-and-plunge structure is seen where it should be expected—that is, in the thickest part of the formation or within the bays of the Fountain sea.

All the undulations of the Archean floor might be due to gentle crustal folding during Fountain time. This hypothesis also would provide for the continuity of the "Red Beds" over the eminences. It would make unnecessary the assumption that hills stood out as promontories in the advancing sea and that the shore line was crenulated. It does not, however, account so well for the general cross-bedding, and for the flow-and-plunge structure that so plainly characterizes the places which, on account of the greater thickness of the "Red Beds," are regarded as bays. Except in the vicinity of Boulder there is also a lack of collateral evidence of such crustal deformation. The hypothesis of warping during sedimentation might be used to support the theory of a pre-Fountain peneplain, but it has already been pointed out that the character of the Fountain sediments does not admit of the assumption that they were derived from a peneplain. The Boulder arch itself was probably slowly bulging upward while the "Red Beds" were being deposited. The evidence on this point is given under the discussion of the next higher formation. (See p. 61.)

DEPOSITION OF FOUNTAIN FORMATION.

Generally speaking, the local thinning of the red rock is due to thinning of all the beds rather than to a disappearance of a part of them. Except in the vicinity of Boulder the topmost strata of the formation can be traced continuously from point to point along the line of towering crags, which form the most conspicuous feature of the foothills. The Lyons sandstone shows the same continuity at a higher horizon, and the strata at the base of the red rock are almost or quite as continuous as those at the top. If the contact is followed from canyon to canyon over the intervening spurs, the basal ledge of the red rock may frequently be seen for a mile or more. In almost all such cases the continuity of the stratum at the base is noticeable, although this is not quite universal, as there seem to be

a few places where the beds at the base abut against a low rise in the granite surface. At such places the contact appears to shift to successively higher beds of the red rock.

DEPOSITION OF LYONS SANDSTONE.

The change which brought about the deposition of the Lyons sandstone was comparatively abrupt. Only a short time after the deposition of rough arkose, the sediments were composed of thoroughly assorted clean-washed quartz sand. The details of structure also changed to a neat cross lamination, producing flags of a uniform thickness and large area. Most of these flags which are now exposed dip east at a smaller angle than the true bedding; that is to say,

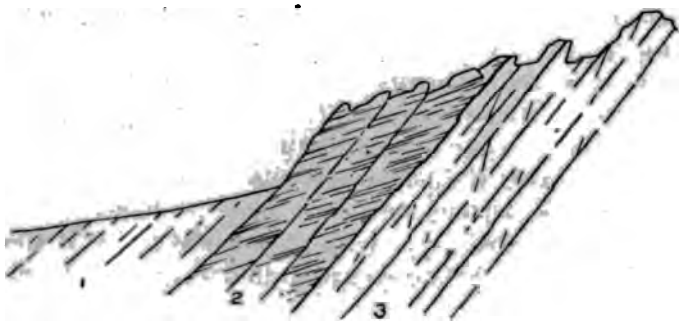

FIG. 6.—Position of cross-bedding of the Lyons sandstone. 1. Lykins formation. 2. Lyons sandstone. 3. Fountain sandstone.

if the true beds were again horizontal the cross-bedding would dip west, or toward the old shore. (See fig. 6.)

BAYS AND BARS.

The nature and peculiar bedding of these sediments indicate that the shore line was indented on the west by a bay, and that this bay was spanned by a bar of clean sand—the formation known as the Lyons sandstone. Most of the sandstone now exposed was deposited on the landward side of the bar and dips toward the land. The area here discussed embraces parts of two such bays, separated by a salient point between Boulder and Gregory creeks. (See fig. 7, p. 60.) In front of this headland the peculiar sediments ascribed to bar building are absent.

Not only are the bar sands absent from this locality, but the headland seems to have been eroded and to have furnished a part of the material for the bars. It can not be stated beyond doubt that there was such erosion, because, at the place concerned, the upper beds of the red rock are poorly exposed. It is certain that just west of

Boulder the red rock is much thinner than it is a short distance to the north or south. From appearances it is probable that this decrease in the thickness of the formation is due in part at least to thinning of the individual beds, but it is not plain that the whole difference can be thus accounted for. In so far as the upper beds fail to cross the arch,[a] it is most consistent with the physical history to assume that they were eroded from the headland which, without doubt, projected at this point when the bars of the Lyons sandstone were being deposited. Cliff erosion on the salient would certainly be expected from the relative position of the headland and bar.

These bays could not have resulted from the continued submergence of an uneven land surface. The headland at Boulder was plainly due to warping resulting from north-south stress. It corresponded in position to the Boulder arch, which has been subjected to repeated upward warping. As the sediments became thinner at this place and as a headland appeared immediately after their deposition, while sedimentation continued to the north and south, the cause of all these phenomena was no doubt crustal deformation.

The conclusion that the Lyons sandstone is the sediment of bars rests finally upon the position of its cross lamination, which in general dips toward the shore. This necessitates either the above-stated hypothesis of bars or that there was land farther east from which sediments were derived. The supposition that there was land farther east is entirely without support. The hypothesis that the sands were laid down in the form of bars is supported by the nature of the sands and by their absence at the most probable headlands, from which, in part, the shore drift should have been derived.

It is to be remarked that the dip of the cross-bedding at Gregory and Boulder canyons, where the formation abuts against the supposed headland, is away from the mountains. The Lyons sandstones exposed at Boulder and Gregory canyons are in immediate contact with the old headland, and therefore represent the seaward side of the bars. From the nature of the contact of a bar with the salient from which it springs, it is the seaward front and not the inside or landward slope of the bar that is tangent to the land. (See fig. 7, p. 60.) Whatever cross-bedding existed on this seaward front must, of necessity, have dipped seaward. Therefore the relative eastward dip of the cross-bedding at these places is in exact accord with the theory of the deposition of these sands in the form of bars.

The supposition that two bays were separated by a salient between Boulder and Gregory creeks rests upon (1) the absence of bar sediments at that point, (2) the probable erosion of the topmost red

[a] See Eldridge, G. H., Geology of the Denver basin: Mon. U. S. Geol. Survey, vol. 27, 1896, p. 110.

rock, (3) the eastward dip of the cross-bedding of the beach sands nearest to this point.

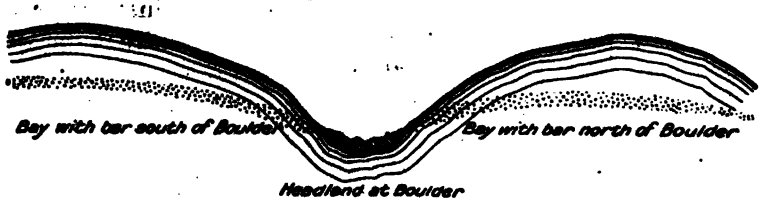

FIG. 7.—Shore line during the deposition of the Lyons sandstone.

From the above reasoning it follows that the Lyons sandstone should be intermittent in its distribution alongshore after the manner of bars. This is true. They should also form a relatively narrow reef-like zone, and, if followed outward from the old land, the direction of dip of the cross lamination should be reversed. Along this line no direct evidence is at hand.

MIGRATION OF BARS.

A bar extending across a bay retreats landward with the recession of the cliff from which it springs. This retreat is accompanied (1) by progressive deposition on the landward side of a series of layers which dip toward the land, and (2) by erosion on the seaward side, which results in the removal of the upper part of layers previously deposited.[a] (See fig. 8.) The first effect is exemplified here in the prevailing dip. The second is beautifully shown wherever there is a good contact between the Lyons sandstone and the next higher formation. The bottom of the Lykins is occasionally exposed as a clearly defined surface against which the clean-cut flags abut at an angle which may reach 36°. (See fig. 6, p. 58.)

FIG. 8.—Section of a linear embankment retreating landward. The dotted line shows the original position of the crest. (After Gilbert.)

This process of building bars of clean-washed sand, which are shifted gradually landward and truncated, implies a considerable stability of the land with reference to the sea level, though it is not prevented by moderate sinking. In the epoch here considered, not only the well-assorted, clean-washed, creamy sands, but also the shaly sands which follow, indicate quiet conditions and freedom from crustal deformation.

[a] Compare Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890, p. 53. The conditions here described are discussed by Gilbert, as exemplified in the mole inclosing Toronto Harbor. Fig. 8 is taken from this discussion, p. 56.

LYKINS SEDIMENTATION.

While the bars of Lyons sands were being truncated sediments could not be deposited on the truncated base unless they were coarser than the sand which had been removed. Later, however, this surface subsided to such a depth that it was buried by a sandy and highly ferruginous mud.

The deposition of the other sediments of the Lykins formation required similar depth, and during this time there was nothing peculiar in the shore conditions. Probably at this time while the sea bottom was depressed so that mud was deposited in places from which sand had been removed, the relief of the land was reduced, and thus the supply of coarse sediment was checked. During much of Lykins time the sea was so deep that ripple marking and cross-bedding did not take place, but toward the close both are apparent.

LYKINS WARPING.

At Twomile Canyon the cross-bedding near the top of the series again indicates deposition on the landward side of a bar. It may be inferred from this that headlands were again being eroded, and this assumption is borne out by the nature of the sediments, which are coarser near the top. The headlands were probably caused in part by a gentle warping, which harmonizes with indications of crustal movement at the close of the Lykins, which may have caused a slight unconformity between the rocks of this epoch and those of the Morrison. The brown sandstone at the top of the Lykins is not of uniform thickness. (See p. 25.) The exceptional abruptness, also, with which at many places the highly ocherous rocks give place to the gray above, at least raises the question whether there might not have been a transitional stage whose record is lost. As pointed out in the description of the stratigraphy, such beds, transitional in color and texture, appear in a number of places.

Uplift of the Boulder arch.—While clear and definite indications of a general unconformity at the top of the Lykins are wanting, there is decisive evidence that the Boulder arch was uplifted and eroded. The "crinkled" sandstone approaches to within a few hundred feet of the south side of Gregory Canyon, maintaining about its usual distance above the Lyons. The same conditions are found on the north side of Boulder Creek, but for more than half a mile north of Gregory there is no trace whatever of the Lykins. The uplift of the fold north of Gregory Creek was almost equal to the combined thicknesses of the Lykins and the Morrison. The former is normally from 600 to 800 feet thick and the latter is not less than 150 feet. Only the topmost beds of the Morrison probably covered the arch and are concealed beneath the talus of red rock.

MORRISON SEDIMENTATION.

The Jurassic in this vicinity is represented by but one formation, the Morrison. The physical history of the period is not well indicated within this area. Fossils have not been found here, but those collected at other places show that the water of the Morrison sea was fresh. On the north and south, therefore, the ocean was shut out by land barriers extending east from the mountains to other land at an unknown distance.[a] At first the Boulder arch stood less than 100 feet above the water, and its height above the sea was gradually reduced by subsidence or by a change of the lake level. The arch was probably covered by the upper beds of the Morrison.

At a distance from the vicinity of the Boulder arch, the clays at the summit of the Jurassic have a nearly but not altogether constant thickness. If present at all between Gregory and Boulder canyons, they are very thin. Erosion is plainly indicated. The fresh-water lake gave way to land. Paleontologic evidence taken from broader areas indicates that this area was land through the whole of Lower Cretaceous time. The relief of this land surface was low. This is inferred not only from the fact that no valleys appear in its present buried surface, but also from the nature of the sediments when it was again submerged.

DAKOTA SEDIMENTATION.

At the beginning of Upper Cretaceous time the sea again covered this region. The first bed of sediments laid down contains much sand, but consists largely of very resistant and generally well-rounded pebbles of quartz, quartzite, jasper, and chert. The selection and separation of such materials from the waste of the previous land surface are consistent with low relief and deep weathering.

These facts are best explained by assuming that these residual pebbles of very resistant minerals were embedded in the surficial deposits of the submerging land. The soil sheet was worked over and assorted by wave action and these large pebbles deposited near shore. An unknown quantity of such deposits, brought down by streams from the land to the west, is doubtless mingled with the material derived from the submerging mantle rock. The finer and much more abundant products of decomposition were necessarily deposited farther seaward. According to this explanation this conglomerate is a shore phase of the lowest Dakota beds.

Mingled with the hard pebbles are occasional fragments of rocks, such as limestone, clay, and feldspathic rocks, that would readily yield to weathering and wear. These may have come in part from

[a] Emmons (op. cit., p. 24) suggests that the Morrison lake may have extended from near the northern boundary of Colorado to the latitude of the Raton Hills.

cliffs that were cut from low hills of the old land surface. They also suggest what they alone would not be sufficient to prove, namely, that the oncoming of the sea was accompanied by some warping and steepening of the land; but of this there is other evidence, as follows:

Before the close of the Jurassic the Boulder arch was covered by sediments, which were not entirely eroded away during the succeeding land epoch, showing that the land must have been very near the sea level. The absence of the lowest Dakota near Boulder, however, shows that just before the Dakota sediments were laid down elsewhere there was a differential subsidence amounting to a renewal of deformation along the old line.

BENTON SEDIMENTATION AND UPLIFT.

As a result of deepening of the sea, decrease in the relief of the land, and gradual removal of the shore, the Dakota sands were followed by the Benton shales, not suddenly, but after some alternation of sediments. The arching was again strongly renewed, this time between Sunshine and Boulder canyons. Erosion cut away the entire Dakota, but there is nothing to show whether the Jurassic was further wasted. The uplift remained above water until very near the close of the Benton epoch. Only the very latest beds of the Benton are continuous over it. The amount of uplifting at this time was therefore approximately equal to the combined thickness of the Dakota and Benton. The average thickness of these formations north and south of Boulder is not less than 700 feet.

NIOBRARA SEDIMENTATION.

The deposition of the Niobrara was not accompanied by noteworthy physical conditions, except those attributable to diminishing sediment, removal of shore, or deepening water. There is no evidence in this area of any disturbance at its close.

PIERRE SEDIMENTATION AND FOLDING.

As a single mass of shale, the Pierre is extraordinary on account of its great extent and thickness. A discussion of the factors adequate to produce these results would not be possible from observations in this small area. It is safe to assume that during Pierre time there was a steadily sinking sea bottom and a steadily rising land that had a relief sufficiently low to allow thorough decomposition. The sinking area on the east and the rising area on the west were necessarily separated by a monoclinal fold of increasing height. It is highly probable that this fold lay along the line of the present foothill belt and that although its dip was more gentle than that of the present great monocline it determined the line along which the forces

of mountain making later gave form to the steep monocline which now follows the eastern border of the Archean belt.

The record of changes on the Boulder arch continues legible during a considerable fraction of Pierre time. The arch continued to rise relatively—that is, it sank less rapidly than the adjacent areas. This is shown by the position of the Hygiene sandstone. At Boulder this stratum is separated from the Niobrara by barely 1,000 feet of Pierre shale. Five miles farther north the same shales are 3,000 feet thick, showing a relative rise of the Boulder arch amounting to 2,000 feet during the first half of the Pierre epoch. The record of the latter half of Pierre time is not clear, because there are not enough outcrops to allow satisfactory determinations of thickness over the Boulder arch. The shale-making conditions were not uniform throughout the epoch. The deposit of so thick and continuous a sandy stratum as the Hygiene sandstone probably indicates a temporary dominance of the uplifting forces over subsidence.

FOX HILLS SEDIMENTATION AND LARAMIE UPLIFT.

There were no noteworthy physical changes at the beginning of or during the Fox Hills epoch, except variations similar to those which occasioned the sandy layers in the Pierre. The Laramie indicates a general uplift, both by the coarser character of its sediments and by its beds of coal.

SUMMARY OF HISTORY OF THE BOULDER ARCH.

With the exception of the growing monocline which separated the sinking sea bottom on the east from the rising land on the west, the Boulder arch is the index of all the crustal deformation definitely recognized as occurring in this area before the Rocky Mountains were formed. It is noteworthy that the forces which caused it acted in a north-south direction. In the later deformations east-west forces were completely dominant.

From the evidence given above, the successive rises of this east-west anticline may be summarized as follows: During the Boulder and Lyons epochs there was a rise which may have reached the maximum limit of 1,000 feet. (See p. 55.) The axis of this movement was south of Boulder Creek. At the close of the Lykins there was a further elevation, approximating 850 feet. (See p. 61.) In the interval between Jurassic and Dakota there was a relative elevation whose minimum may be placed at 25 feet. The uplift at this time may have been broad, extending from south of Gregory Creek to a mile north of Sunshine Canyon. At the close of the Dakota the minimum uplift was 700 feet along an axis between Sunshine and Boulder creeks. In the first half of the Pierre epoch the further rise amounted to 2,000 feet.

Maxima are given in some cases, and minima in others, but the sum of all the above amounts, which is 4,575 feet, may be taken as an approximation to the total elevation of this anticline.

An examination of the geologic map shows that there has been a great depression of the Boulder arch since the formation of the Hygiene sandstone. If the strata of the foothills and the plains were now deprived of their eastward dip, the upper beds would show a pronounced east-west syncline on the site of the former anticline. Even in the lower beds little of the former east-west anticline remains. Since the Hygiene sandstone is the youngest formation that gives evidence concerning the age of Boulder arch, the date of this flattening can not be fixed within narrow limits. A similar arch, stretching eastward from Golden, about 17 miles to the south, can be studied in more detail, because of the presence of younger strata. Emmons[a] and Eldridge[b] held that the flattening of the Golden arch may have occurred in Denver time, and perhaps was due in part to the extravasation of basalt along the line of the old anticline. The two arches had almost the same history, and the sites of both are marked by volcanic extrusions. Cross assigns the eruptions to the same epoch. Whatever causal relation exists between the extrusions near Golden and the flattening of the Golden arch may also be assumed to exist between the Valmont dike and the depression of the Boulder arch.

POST-LARAMIE HISTORY.

Post-Laramie history is recorded in the deformations incident to mountain making and in the forms due to erosion. The time of most of the events can not be accurately determined by local evidences.

Topographic features due to erosion are presumably in the main Quaternary. They indicate continuous degradation that has resulted in a series of river terraces. With the exception of the small fragments of the loess sheet (see p. 35) and a few isolated alluvial fans, there are no fluviatile deposits except those left by degrading streams. There is no broad sheet, such as that of the High Plains,[c] implying an epoch of stream aggradation. Everywhere the stratified rocks of this margin of the plains have been neatly pared off by meandering streams. The sheets of gravel which cover the planed surfaces are such as down-cutting streams should be expected to leave.

[a] Mon. U. S. Geol. Survey, vol. 27, p. 50.

[b] Id., p. 100.

[c] Johnson, W. D., The High Plains and their utilization: Twenty-first Ann. Rept. U. S. Geol. Survey, 1901, pp. 651–656

No features in this area require for their formation streams larger than the present ones. The present Boulder Creek is a degrading stream, with moderate meanders and a broad flood plain sloping toward the stream. Where it reaches the bluffs which front its terraces the river is cutting into the bed rock and planing off a surface on a level with the bottom of its channel. On this planed surface it is depositing a sheet of heavy gravel and finer alluvium, similar both in character and thickness to the sheets which everywhere cover the mesas and other terraces. (For a more explicit comparison see p. 14.) That the streams which caused the present plains topography were degrading their channels is plainly shown by two facts: (1) The débris sheets have a uniformly limited thickness, and (2) the terraces always slope toward the streams to which they were flood plains. This continuity in the cutting by the streams gives to the erosional history of the district a unity which makes subdivision impracticable.

This uniformity of erosional history near the foot of the mountains is in contrast with the more complex history of the plains farther east,[a] where the denuding processes have plainly been interrupted by aggradation one or more times. The obvious inference is that the entire recorded erosional history of this narrow belt must be matched with the last epoch recorded on the plains, which is one of stream degradations.[b]

It is entirely natural that when the character of streams is changed, whether from aggrading to degrading, or the reverse, the belt nearest the mountains should be the first to suffer complete obliteration of the records of former conditions. The rivers may recently have acquired increased cutting power by an uplift on the west that increased their grade, or by an increase of rainfall, or, as Johnson suggests, by a mere cooling of the climate, which would decrease evaporation. In any case the upper course must first be cut down and in this the records of former aggradation will first be erased. If the change of stream habit be the reverse, the prompt burial of features near the mountains is equally well understood. If the climate is moderately arid, as in the area under consideration, there is an additional reason for the prompt erasure of aggradation records near the mountains, as running water is more abundant there, many streams actually losing volume as they proceed.

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[a] Johnson, W. D., op. cit., p. 628; also Emmons, S. F., op. cit., p. 255.

[b] As to the geologic data of this epoch Johnson says (op. cit., p. 630): "The beginning of the final and present degradation, during which the smoothness of the Great Plains has been in large part destroyed and their surface lowered, with the exception of the sod-covered plateaus of the central zone, doubtless dates from the opening of that period of climatic oscillations in the Pleistocene which, in the Great Basin region of Utah and Nevada, gave rise to repeated floodings of large areas and the creation of lakes."

ECONOMIC GEOLOGY.

WATER.

SURFACE ZONE.

Ground water in the area under consideration is found at moderate depths. Over the well-drained parts of the plains it is commonly encountered at depths of from 10 to 20 feet. Since the bed rock is in large part relatively impervious shale, the slope of the ground-water surface is very similar to the slope of the ground. One bluff 40 feet high is quite dry at the base, but on the terrace above, less than 200 feet from the bluff, water is found at a depth of 12 feet. The surface shales are everywhere more permeable than the unweathered rock below, and the movement of water in them is freer than at greater depths. In drilling oil wells, therefore, it is found necessary to case off this surface water.

DEEPER ZONE.

Below this superficial zone, which is 25 to 50 feet thick, the shale is so dense and the consequent movement of the water so slow that wells are spoken of as "dry." At irregular intervals within the shales, as deep as the formation has been explored in drilling for oil, are sandier beds of limited lateral extent. In these the movement of the water is more rapid, and after drilling through them it is sometimes necessary to case off the water from these deeper sources. When the character of the water is suitable, these beds might afford supplies for deep wells, but the water is not infrequently slightly saline, and it may be a brine. Flowing wells are not obtained from these sources in the Pierre shales, nor are they expected, on account of the limited lateral extent of the sands and their close texture where unweathered.

FLOWING WELLS.

South of Burnt Knoll, about 6 miles southeast of Boulder, a faint flow of water was obtained from the Laramie at a depth of 80 feet. A similar flow was obtained at Lafayette, 11 miles east of the foothills, at various depths between 400 and 700 feet. It was encountered while drilling for oil.

At the north end of the field the Stuart well, drilled for oil, encountered abundant water in the Morrison formation. At last accounts (April, 1904) the well was still flowing. It is located on the Pierre shales, one-half mile east of the Dakota outcrop (SW. ¼ of sec. 5, T. 2 N., R. 70 W.). The dip of the beds at the surface is here 26°. The succession of strata passed through leaves no doubt

that the Morrison was encountered at a depth of 1,336 feet. If all the beds passed through dip at an angle of 26° and have the thickness given above, under the heading "Stratigraphy" (pp. 20 et seq.), the Morrison should have been found at a somewhat greater depth than 1,336 feet. Probably at a short distance below the surface the dip is less than at the surface, where it has been steepened by the process described above as tending to produce a fan structure. The water is from a horizon about 60 feet below the top of the Morrison; it is therefore from one of the upper beds, probably from the "Saurian" sandstone. This supposition is supported by the fact that the water comes from yellow sand. Presumably the lower and larger Morrison sandstones, and especially the basal stratum, would yield water still more copiously. This assumption is supported by observations on the small stream flowing east over the Lykins and Morrison outcrops in Lykins Canyon. The channel when examined was dry as far as the outcrop of the Morrison. At this point water appeared within a few yards and there was a flowing stream. No well, however, has reached these lower beds, the Stuart being the only one which is known to have entered the Dakota. The high dip of the strata makes it impracticable to obtain water from even the best beds of the Morrison except within a narrow strip east of the foothills.

WATER IN THE DAKOTA.

Water was obtained in the Stuart well from the Dakota, but not in amount to be compared with that from the Morrison. The relations of the Dakota are not favorable to any great water supply for northern Colorado. The hardness of the formation causes it to outcrop in a single rocky ridge, which quickly sheds the precipitation and is unfavorable to percolation. True, the outcrop is crossed by streams flowing from the mountains, but even this intake must yield a small supply on account of its extremely restricted area. Moreover, the Dakota sandstone is practically sealed below by relatively impervious shales and clays, and therefore can not receive much of the water that penetrates the lower strata which outcrop west of the Dakota hogback. If the Dakota of northern Colorado be compared in these various respects with other well-known water-bearing strata—for example, the Potsdam of central Wisconsin, or even the Dakota sandstone of the Black Hills—its area of intake will be seen to be very small and topographically unfavorable to percolation. The slow inflow into the Stuart well from this formation also indicates that it is denser than the sandstones of the Morrison. The Morrison sandstones, though much thinner than the Dakota, outcrop in a valley, or on the western slope of the great ridge of which the Dakota forms the crest. In either case their

edges are generally covered with a sheet of loose waste, favorable to percolation.

BUILDING STONE.

In the matter of building stone the area here described is typical of a much longer stretch of the foothill belt of which it forms a part. Most of the formations yield valuable economic products, the building stone coming mainly from strata not younger than Jurassic.

GRANITE.

Within the area mapped granite has not yet been quarried or even studied with reference to its use as building stone. Apparently, however, the area may furnish granite for architectural purposes of suitable grain, color, strength, and size of block.

THE RED ROCK.

The great mass of the Fountain red rock is not appropriate to building purposes. Locally, however, there are, near its summit, beds of the finest quality of structural stone. One-fourth mile north of Fourmile Canyon a quarry has recently been opened at this horizon to supply material for the new Episcopal Church at Boulder. In contrast with the prevailing arkose character of the Fountain, these exceptional beds are even-grained, quartz sands, containing only here and there minute grains of feldspar. Biotite scales are rather plentiful, and are arranged parallel to the bedding, so that transverse faces show only very minute black lines, which are not sufficiently prominent to indicate the position of the bedding except by very close examination. The stone is of a light pink color, which runs uniform so far as the quarry referred to has been worked. Except in the biotite, all the contained iron is supposably in the peroxide form, and the stone contains nothing to cause a stain upon exposure to the weather. The stone is massive and must be dressed on all sides of the block. Blocks which dress 2 or 3 cubic feet are frequent. The strength has not been tested, but there is no doubt an ample margin beyond the needs for all ordinary building purposes.

LYONS SANDSTONE.

This is by far the most abundant rock of economic importance within the area described, and probably within the foothill belt north of Denver. The name "creamy" sandstone, which is often applied to it, is unfortunate, for it is distinctly pink. It varies somewhat in

color, however, and at one extreme it may reach an almost creamy tint, while at the other it may be red. Still, the great mass is so uniform that stone from many quarries might easily be used in one building. The standard color of this stone has more of the creamy and less of the vermilion tint than that of the rock quarried from the Fountain sandstone. It does not develop any discoloration in the wall.

In composition the stone is of the purest even-grained quartz sand, its siliceous cement deriving its color from ferric iron. The cement is so abundant as to make the stone quartzitic, and it is known in the trade as a crystalline sandstone.

The distinguishing feature of the structure of this stone is its delicate lamination and perfect partings in the quarry. Fifty laminations to the inch may sometimes be readily distinguished, but at a distance of a few feet the lines are invisible and the stone has a uniform tint. Occasional stronger lines may make the lamination more prominent.

In the quarry the stone parts perfectly into thicknesses varying from a fraction of an inch to more than a foot. Flagstones of convenient thickness and having as much as 60 or even 80 square feet of surface may be obtained. The flagstone industry has its center at Lyons, about 3 miles north of this area. Near Boulder the thickness of the beds is generally greater, and the stone is commonly quarried for building. The blocks for this purpose may be as thick as 15 inches, but the average is probably not above 8 inches. As the bedding planes are perfectly smooth and parallel, the blocks require dressing on four sides only. Both the convenience and the strength of this stone cause its general use in foundations in the near-by towns and cities. It is also used for the superstructure in some large and handsome buildings. The stone is likewise in common use for sills and curbings. As pointed out on page 24, the bedding planes observed in nearly all quarries of the Lyons sandstone are those of the cross-bedding, having had a dip toward the shore on the west when deposited.

The amount of this stone in northern Colorado is enormous. If its workable thickness in this area averages 50 feet and if quarries be worked 100 feet down the dip of the stratum, each linear mile of the foothill belt would yield 1,000,000 cubic yards of stone.

RED SANDSTONE OF THE LYKINS.

Stone from this series of beds is not quarried in this area. At a few places the Lykins yields a very fine-grained and close-textured red sandstone, easily worked and readily obtained in large blocks.

The same stone occurs abundantly within this area, but, whether from the repeated warping of the Boulder arch or from the diagonal compression resulting in the échelon folds, it is too much fractured to be obtained in large blocks. This is the case at each of the few places where it has been prospected.

WHITE SANDSTONE OF THE JURASSIC.

The chief quarry opened in the lowest Morrison sandstone stratum is known by the name of Doctor Bond. The product of this quarry is a slightly calcareous sandstone of moderate strength, of a gray color, inclining toward yellow rather than blue, and having no lamination or subordinate bedding planes within a 10-foot stratum. It is not always free from iron stains, which may appear in the quarry or may develop after building into the wall. Large dimension stones are readily taken out and easily worked. The bed in which this one quarry is opened has a fairly uniform thickness and character for many miles. It is probable that in the future this stone will be quarried much more extensively.

BUILDING STONES FROM THE CRETACEOUS.

But little stone is quarried from strata younger than Jurassic. The Dakota is very strong, but difficult to work, the blocks generally requiring dressing on all sides. Within this area it need scarcely be taken into account, as it is accompanied by other formations containing such vast stores of more desirable material.

The massive summit sandstone of the Fox Hills is quarried in considerable quantity farther north. It is but little exposed within this area, and where found it is commonly too weak for structural purposes. Beyond the eastern border of the area it is not improbable that this stone will be found locally of fair quality.

The white sandstone of the Laramie can scarcely be called a commercial product. It is present in great quantities and easily taken out and worked in blocks of large dimensions, and a few houses have been built of it. Its strength, however, is small, and it is much stained with iron.

GRINDSTONE.

The white sandstone at the base of the Morrison, which is used for building purposes as described above, is locally used for grindstone and enjoys considerable favor. About a mile north of Altona a quarry, known as the "Grindstone quarry," has been opened by Peter Haldi, of Altona. The few grindstones from this source which

are in regular use have been dressed by hand. To all appearances they are doing their work in a highly satisfactory manner. The grain is fairly sharp, the cement is very slightly calcareous, and the stone is easily dressed. Several much-used surfaces seemed to be clogged with the muddy products of the abrasion of the stone itself, but the users maintain that such an occurrence is the result of improper use. The crude methods of quarrying have produced rather small and ill-shaped blocks, but, judging from the same stratum where quarried for building purposes, this does not indicate any fault in the stone itself. Suitable shapes and sizes can no doubt be easily obtained.

LIME.

The production of quicklime is carried on to a limited extent. The stone used is mainly from the basal stratum of the Niobrara. At various places also the limestone lenses of the "crinkled" sandstone in the Lykins have been utilized; occasionally also the beds in the Morrison. The limestone of the Niobrara is highly magnesian[a] and very dense. On account of its density it does not calcine very readily and the large percentage of magnesia makes a "cool" lime.

CLAYS.

OPPORTUNITIES FOR THE BRICK INDUSTRY.

The brick industry at Boulder is already large and there is no necessary limit to its expansion, except the size of the market, the raw material being presumably inexhaustible. It appears, however, that the Pierre shale, which is the chief resource for red brick, is not entirely uniform in its brick-making properties. Yards within the limits of Boulder produce bricks differing in shrinkage, density, and strength. As the surficial aspect of the Pierre shales is highly uniform for long distances, it is very probable that laboratory tests will come into general use in the locating of yards as the industry expands.

Red brick must always constitute the chief product of the clay industry. Three plants, each with a capacity of 20,000 bricks a day, are operating steadily at substantially full capacity. These are all using the Pierre shale and are practically within the city of Boulder. The Benton has not been used. At present all the pits are on mesa edges, the mesa in each case being from 30 to 50 feet higher than the adjacent lowland. While such a situation may be desirable from

[a] An analysis of Niobrara limestone is given by Eldridge, op. cit., p. 67. It shows 18.03 per cent MgO.

the standpoint of moisture conditions, it is mainly a matter of convenience, and must not be understood to be necessary. There is nothing to bar from future use any part of the shales of the Pierre belt as shown on the map.

SHALE SUPPLY.

At each of the three pits the shale is covered with the rough mesa gravel, which at one place has a thickness of 15 feet, and which is removed. Where the mesa gravel is almost absent, the clay resulting from decomposition of the shale may be as thick as 2½ feet, but this is of no significance in the manufacture of brick. Where the mesa gravels are thick, the clay is wanting. The shale is almost free from lime, though some highly calcareous nodules occur, sometimes containing fossils. Occasionally, also, a thin plate of shale is dark and hard with impregnated iron, but the quantity of such is almost negligible.

If the shale is not reduced to clay, it is not to be understood that it has been entirely unaffected by weathering. Its bedding remains perfect and it is apparently unweathered, but where excavation is deep the color is always observed to change from a greenish drab above to something darker (commonly called "black") below. Throughout the belt underlain by the Pierre, though the normal color varies, the surficial zone shows almost the same greenish-drab color. This ends abruptly at a depth of 30 feet, more or less. In the black shale (or "slate") below lamination is less apparent, and large masses break with a conchoidal fracture. Naturally the concretions are not observed within this fresh mass, as they are in the partly weathered zone, from which they roll out upon blasting. The shales of the upper zone have little grit when tried between the teeth.

A partial analysis of the shale from the Austin yard, made by Prof. C. S. Palmer, is given by Mr. Austin, as follows:

Analysis of shale from Austin yard, Boulder.

	Per cent.
SiO_2	60.0
Al_2O_3	18.0
Fe_2O_3	4.75
MgO	2.0

An analysis of a single selected lump (not a mixed sample) of the shale from Mr. Lee's yard, made by Mr. W. B. Stoddard, of Boulder, and furnished by Mr. Lee, is as follows:

Analysis of shale from Lee yard, Boulder.

	Per cent.
SiO_2	63.309
Al_2O_3	14.380
Fe_2O_3	6.270
FeO	.859
CaO	1.810
MgO	2.570
Na_2O	2.190
K_2O	1.280
Loss by drying	2.053
Loss by ignition	5.223
	99.944

PROCESSES OF BRICK MANUFACTURE.

The material is first loosened by blasting. Concretions are thrown out, chiefly to save wear in the crusher. They are said to be harmless in the brick if crushed sufficiently fine. In one of the three pits the black shale below is not reached. In another it is reached at the bottom, but not used. At the Austin works, on the north side of the city of Boulder, it is taken out and used along with the shale of the higher zone. It is harder, drier, and less plastic, and is therefore mixed with the partly weathered material. When thus mixed, no difference in the resulting brick can be detected, and there is no inconvenience in the manufacture. If properly ground, the unweathered black shale may be mixed with the weathered shale in equal parts. The blasting of this fresher shale in the autumn and its weathering or slacking through the winter has been tried, but no notable difference was produced.

The shale is crushed, screened, and pressed dry. Generally the moisture of the bank is sufficient for the pressing process. When the shale is too dry it is moistened in the crusher. No mud bricks are made.

The burning is in up-draft kilns, which generally have permanent walls for two-thirds or three-fourths of the height. One-half to two-thirds ton of local (Marshall or Louisville) coal per 1,000 bricks is used in the burning. Mr. Austin has installed a gas plant, and the project of burning with gas may be said to be on trial.

The shrinkage in both drying and burning of the best and strongest samples tested was but one-sixteenth inch in the height of the brick (4 inches), or less than 3 inches in the height of the kiln. Either by reason of difference in the clay or in the burning, this shrinkage varies at other yards to a maximum of three-sixteenths of an inch per brick, or 7½ inches in a kiln 40 bricks high.

QUALITY OF THE BRICK.

Standard tests made upon the red bricks by Prof. L. Duncan, of the University of Colorado, show an average crushing strength for the best brick equal to 4,100 pounds per square inch.[a] Supported at the ends (supports 6 inches apart) and loaded at the center, the same bricks showed a maximum fiber stress of 498 pounds per square inch. The same bricks absorbed water equal to 11.2 per cent of their weight in fifteen minutes, 11.6 per cent in thirty minutes, and 11.9 per cent in twenty-four hours. The promptness with which these bricks absorbed nearly the whole amount of water which they were capable of containing indicates largeness of the individual pores. The more rapidly water is absorbed, the more rapidly it is lost, and the probability that a sudden freeze should find the pores of these bricks filled with water is very small. This statement does not apply to bricks laid below the water line.[b]

No attempt has been made to make vitrified brick on a commercial scale at the Boulder yards. Experiments have been carried on in this line, and a very good brick resulted, but the shrinkage was great. In two tests it was seven-sixteenths inch and one-half inch in the height of the brick (4 inches).

BRICKS OF LIGHT COLOR.

For several years past small quantities of light brick of a prevailing creamy color have been burned at the Boulder yards from clay brought by wagon from the coal-mining districts to the southeast. The first clay for this purpose was brought from Coal Creek. The largest amount has come from an abandoned coal mine at Marshall, from 3 to 4 feet of the clay being taken from the floor of the mine. More recently a number of samples from near Burnt Knoll have been tested, and encouraging results are reported.

Tests of light bricks from the Marshall clay gave a crushing strength about equal to that of the best red brick (4,090 pounds per square inch), a maximum fiber stress about two-thirds as great as that of red brick (332 pounds per square inch), and absorption slightly greater than that of the red bricks (12.5 per cent in twenty-four hours).

Red brick sell in Boulder at $7 to $9, the last-named price being for facing brick. The common price f. o. b. for shipment is $10

[a] This may be compared with the strength of one of the best-known building stones of the United States, the Bedford limestone of Indiana, which showed, in 17 tests, an average crushing strength of 4,326.7 pounds per square inch.—Twenty-first Ann. Rept. Indiana Dept. Geol. Nat. Resources, p. 317.

[b] See Buckley, E. R., Building and ornamental stones: Bull. Wisconsin Geol. and Nat. Hist. Survey No. 4, 1898, p. 20.

per thousand. Buff brick have not been exported. They sell in Boulder at $20 per thousand.

Just beyond the western border of the area, near Sunshine, is a deposit of kaolin, much of which is to all appearances very pure. Probably the deposit is due to the alteration of feldspars in a pegmatite dike. The clay is white and without grit. Some of it is stony and contains kaolinite crystals. Upon grinding and wetting it becomes thoroughly plastic.

COAL.

A small part of the northern Colorado coal field lies within the area here described. The whole field was carefully studied by Eldridge,[a] who has described the structure, discussed the quality of the coal, and correlated the seams of the different districts. Since the publication of his work, in 1896, several new mines have been opened, but these have revealed no structural relation not known and discussed in Monograph XXVII. The reader will find in that publication substantially all that is known in regard to the geologic relations of the coal.

OIL AND GAS.

SURFACE INDICATIONS.

The development of oil and gas in the Boulder area began in 1901, though their presence was suspected and rumored as early as 1867.[b] The early beliefs were based upon grounds which might now be regarded as far from demonstrative. The subsequent finding of oil must therefore be regarded largely as a piece of good fortune rather than the assured outcome of a safe business venture. The evidence consisted largely in the strongly bituminous odor of the Benton and Niobrara limestones and shales. It was therefore assumed that the strong-smelling rocks were themselves the reservoirs of petroleum, and in the first developments there was no thought of finding oil above these beds. Oil was found several thousand feet higher than these two formations, which have never produced anything of this nature. They have the same characteristic odor near the oil fields and far away. It was reasoned out with equal certainty that the Benton and Pierre shales must produce coal on account of their black color. In fact, it was while prospecting for coal in the Benton that the project of drilling for oil was first conceived.

A second class of surface indications, not found nearer than about 10 miles from Boulder, consists of seepages and "oil springs." The

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[a] Op. cit., p. 345.

[b] A brief historical account of this industry is given by the writer in Bull. U. S. Geol. Survey No. 213, p. 322.

fact that several such, most persistently reported, are on the Archean granite west of the foothill outcrops of stratified rocks shows that

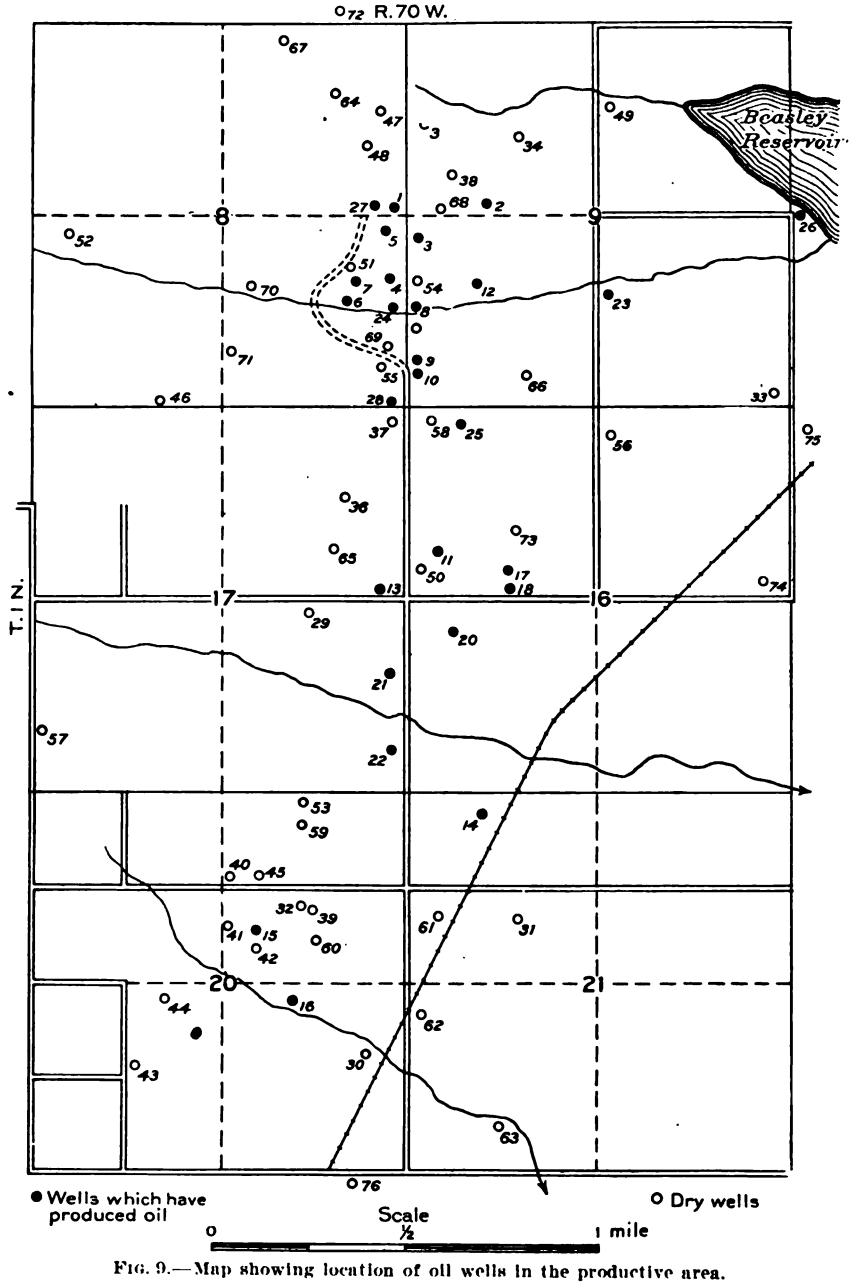

FIG. 9.—Map showing location of oil wells in the productive area.

the distinction between the various kinds of oily substances was *poorly made.* Some of the springs which issue from the Fountain

red rocks are abundantly coated with oily matter at no great distance from the point of issuance, and these springs have been taken very seriously by oil prospectors, but in none of those examined was the odor of petroleum detected. The well-known oil spring on the bank of the Little Thompson, on the Culver ranch, 17 miles north of Boulder, issues from the heavy sandstone member of the Pierre, which has been called in this report the Hygiene sandstone. This is a seepage of petroleum.

OIL-BEARING AREA.

On the evidence of these phenomena, corroborated by the positive behavior of "bobbers,"[a] several wells were drilled. In January, 1901, the McKenzie well, 3 miles northeast of Boulder, struck oil. Since that time there has been more or less drilling from Fort Collins on the north to Golden on the south. Sheet XII of Hayden's atlas has been freely used as "Hayden's oil map," and land underlain by his Colorado group (which includes the Pierre) has been well advertised as lying within "Hayden's oil belt." Development has been successful only within a limited area, the center of which is from 3 to 4 miles northeast of the city of Boulder and a little less than 3 miles east of the foothills. About 100 wells from 300 to over 3,400 feet in depth have been drilled within 5 miles of the McKenzie and about 20 more are scattered over the area between Fort Collins and Golden. Most of the wells (about 70) are within a rectangle 2 miles east and west by 3 miles north and south, comprising secs. 8, 9, 16, 17, 20, and 21, T. 1 N., R. 70 W. of the sixth principal meridian. Within this rectangle are all the producing wells except the Boulder Illuminating, a very small producer in sec. 10 only a few feet from the eastern boundary of the rectangle named, and the Buffalo gas well, which lies 1 mile south of the rectangle.

The following list gives the location of wells, the total depth, and the depth at which oil was found. The accompanying sketch map (fig. 9, p. 77) shows the locations of all wells within the productive area. Some of the dry wells are comparatively shallow; therefore in determining their significance their depths, as shown in the table, should be taken into account.

[a] The exact location of a large proportion of the wells of this field has been fixed by this means. The principle on which the use of the bobber rests is the same as that by which the proper site of a water well is determined by the involuntary turning of a witch-hazel sprout when held in the hand. In two instances, completed derricks have been taken down and removed to distances not exceeding 40 feet, because of the behavior of the bobber after their erection.

Wells in the Boulder district.[a]

WELLS THAT HAVE AT SOME TIME PRODUCED OIL.

No.	Name.	Depth.	Depth to oil.	Location.		
				Section.	Township.	Range.
		Feet.	*Feet.*			
1	Bradford No. 1	2,404	1,810	8	1 N.	70 W.
2	Boulder Valley	2,050 T.	2,010	9	1 N.	70 W.
3	Boulder Valmont No. 2	1,960	1,650	9	1 N.	70 W.
4	Otero No. 1	1,718	1,639	8	1 N.	70 W.
5	Otero No. 3	1,905	1,807?	8	1 N.	70 W.
6	Otero No. 4			8	1 N.	70 W.
7	Otero No. 5			8	1 N.	70 W.
8	Savanna No. 3	1,763	1,584	9	1 N.	70 W.
9	Savanna No. 4	1,475 T.	1,468	9	1 N.	70 W.
10	Savanna No. 5 (Younglove)	2,005	1,980 T.	9	1 N.	70 W.
11	Dismuke	2,070	2,064	16	1 N.	70 W.
12	Orcini			9	1 N.	70 W.
13	McAfee No. 1		2,105 T.	17	1 N.	70 W.
14	McKenzie	2,585 T.	2,537 T.	21	1 N.	70 W.
15	Republic No. 1	961	885	20	1 N.	70 W.
16	Wellington	2,461	2,423	20	1 N.	70 W.
17	Bingham		2,845	16	1 N.	70 W.
18	Arnold	2,820	2,720	16	1 N.	70 W.
20	Wisconsin No. 2	2,900		16	1 N.	70 W.
21	Crawford	2,735 T.	2,683	17	1 N.	70 W.
22	Central	2,621	2,551	17	1 N.	70 W.
23	Two-ten	2,141	2,111	9	1 N.	70 W.
24	Otero No. 2	1,761	1,700	8	1 N.	70 W.
25	St. George			16	1 N.	70 W.
26	Boulder Illuminating	2,700		10	1 N.	70 W.
27	Bradford No. 2	1,720		8	1 N.	70 W.
28	Savanna No. 2	2,300	2,130	8	1 N.	70 W.

DRY OR NEARLY DRY WELLS.

No.	Name.	Depth.	Location.		
			Section.	Township.	Range.
		Feet.			
29	McAfee No. 2	2,700	17	1 N.	70 W.
30	Eagle	2,740	20	1 N.	70 W.
31	Alamo	2,825	21	1 N.	70 W.
32	Great Western	1,600	20	1 N.	70 W.

[a] Numbers in the left-hand column refer to corresponding numbers on the sketch map (fig. 9). Wells *not numbered* are outside the mapped area. Depths marked T were determined *by steel tape measure*; most of the others by cable measure.

Wells in the Boulder district—Continued.

DRY OR NEARLY DRY WELLS—Continued.

No.	Name.	Depth.	Location.		
			Section.	Township.	Range.
		Feet.			
33	Planet No. 2	2,025	9	1 N.	70 W.
34	Searchlight No. 2	2,480	9	1 N.	70 W.
35	Home	1,650	9	1 N.	70 W.
36	Hayden No. 1	2,670	17	1 N.	70 W.
37	Hayden No. 2	2,145	17	1 N.	70 W.
38	Phoenix No. 2	2,400	9	1 N.	70 W.
39	North Star	1,160	20	1 N.	70 W.
40	North Bend	787	20	1 N.	70 W.
41	Republic No. 2	1,008	20	1 N.	70 W.
42	Republic No. 3		20	1 N.	70 W.
43	Homestake	1,100	20	1 N.	70 W.
44	Vindicator	1,300	20	1 N.	70 W.
45	Savanna No. 1	700	20	1 N.	70 W.
46	Boulder Petroleum	1,630	8	1 N.	70 W.
47	Pioneer No. 2	2,160	8	1 N.	70 W.
48	St. Julian		8	1 N.	70 W.
49	Canfield		9	1 N.	70 W.
50	Wood	2,525	16	1 N.	70 W.
51	Otero No. 6, now Rathvon No. 2	[a] 3,575	8	1 N.	70 W.
52	Wisconsin No. 1	2,000	8	1 N.	70 W.
53	Cleveland	2,492	20	1 N.	70 W.
54	Savanna No. 6		9	1 N.	70 W.
55	Savanna No. 7		8	1 N.	70 W.
56	McAfee No. 3	2,580	16	1 N.	70 W.
57	Chicago Banner	2,600	17	1 N.	70 W.
58	Langridge	2,500	16	1 N.	70 W.
59	Sale Boulder		20	1 N.	70 W.
60	Me Edma		20	1 N.	70 W.
61	Keystone		21	1 N.	70 W.
62	Blue Jacket		21	1 N.	70 W.
63	Boulder Basin	3,300	21	1 N.	70 W.
64	Independence	2,550	8	1 N.	70 W.
65	Palm		17	1 N.	70 W.
66	Empire No. 2	2,500	9	1 N.	70 W.
67	La Ford	2,700	8	1 N.	70 W.
68	Craig & Bartlett		9	1 N.	70 W.
69	Savanna No. 8		8	1 N.	70 W.
70	Rathvon No. 1		8	1 N.	70 W.

[a] Drilling deeper.

Wells in the Boulder district—Continued.

DRY OR NEARLY DRY WELLS—Continued.

No.	Name.	Depth.	Location.		
			Section.	Township.	Range.
		Feet.			
71	Hayden No. 3		8	1 N.	70 W.
72	Citizens No. 2	1,850	5	1 N.	70 W.
73	Empire No. 1		16	1 N.	70 W.
74	Anderson	2,684	16	1 N.	70 W.
75	Peoria	2,300	15	1N.	70 W.
76	Phoenix No. 1		29	1 N.	70 W.
(a)	Citizens No. 1	2,500	25	1 N.	71 W.
(a)	Maxwell No. 1		24	1 N.	71 W.
(a)	Maxwell No. 2	2,268 T.	24	1 N.	71 W.
(a)	Pioneer No. 1	2,700	29	2 N.	70 W.
(a)	King	2,870	22	1 N.	70 W.
(a)	Lafayette, Colo	2,325		1 N.	70 W.
(a)	Planet No. 1	700		1 N.	70 W.
(a)	Searchlight No. 1	1,185		1 N.	70 W.
(a)	Monarch	1,500	27	1 N.	70 W.
(a)	Moore	1,500	23	1 N.	70 W.
(a)	Balkan	1,000	29	1 N.	70 W.
(a)	Boulder Valmont No. 1	2,740	22	1 N.	70 W.
(a)	Rose Crude	2,500	29	1 N.	70 W.
(a)	Jasper		10	1 N.	70 W.
(a)	Aurora	3,006	10	1 N.	70 W.
(a)	Amazon		15	1 N.	70 W.
(a)	Carnahan	3,105	18	1 N.	69 W.
(a)	Hoover		35	1 N.	70 W.
(a)	Martin		5	1 S.	70 W.
(a)	Manhattan	3,216	14	1 N.	70 W.
(a)	Olean	2,995	30	3 N.	69 W.
(a)	Hygiene	2,993	36	3 N.	70 W.
(a)	Gardiner	2,300 ?	2	2 N.	70 W.
(a)	Phenomenal	2,150	6	1 S.	70 W.
(a)	Thomas	3,055	19	2 N.	69 W.
(a)	Silver Lake (Stuart well)	1,396	5	2 N.	70 W.
(a)	Sternberg		33	1 N.	70 W.
(a)	Pioneer No. 3		34	1 N.	70 W.
(a)	Prince No. 1		27	2 N.	69 W.
(a)	Prince No. 2		27	2 N.	69 W.
(a)	Buffalo (gas well)	1,800	29	1 N.	70 W.

[a] Wells not numbered are outside the area of sketch map (fig. 9).

The Savanna No. 9, in sec. 9, has reached at the present writing (October, 1904) a depth of 1,840 feet, where a good showing of oil has been encountered.

The Rathvon No. 2 (No. 51 on the map, fig. 9), already the deepest well in the field, is being drilled deeper.

DRILLING IN THE PIERRE.

With few exceptions, the wells thus far put down have been drilled entirely in the Pierre. The exceptions are among the scattered wells to the east, which are on the very similar Fox Hills, or even on the Laramie, but these also traverse the Pierre for the greater part of their depths.

Drilling in this formation is comparatively easy and rapid. It is not uncommon to make 100 feet a day at considerable depths, and this is sometimes done without change of bits. On the other hand, slow progress is made in some beds. The average expense of drilling a well under contract with responsible parties is, at the present time, about $1.65 per foot for the first 2,000 feet. Below that depth the cost is greater. Under such contracts the owner of the well furnishes casing.

Surface water is usually encountered at a depth of about 15 feet and may be found in the first 100 or even the first 200 feet. Below this the wells are commonly "dry" or the seepage into the wells from the dense shales is so slow as to be of no significance in drilling. In isolated cases deep water-bearing strata are encountered, and such water is sometimes salt. At Lafayette, 11 miles east of the foothills, a well that was drilled for oil yielded a vigorous flow of water from several horizons between 400 and 700 feet deep. The oil from another well is mixed with about 10 per cent of salt water, which comes from just below the oil, and a slight admixture of salt water is found in at least one other well.

Many wells are cased only to the depth of the surface water. Others require 1,000 or even 2,000 feet of casing. In general, deep casing is not for the purpose of shutting off water so much as to avoid caving, which is common though not general. It has necessitated the abandonment of several wells.

REPORTS RECEIVED FROM WELL DRILLERS.

By far the most common material reported as passed through is shale or "slate," occasionally varied as "clay" or "soapstone." Sand or "sand rock" is often reported. If it shows oil it is often called "the oil sand," with no particular reference to correlation with the sands of other wells. These sands are described on pages 31–33.

Their composition is generally far from that which the name would suggest. They range from sand to clay, vary in thickness up to a maximum of over 100 feet, have a limited lateral extent, pass by gradations into the normal shale of the Pierre, and occur at any depth. One well may pass through five or six such beds, while another near by may penetrate nothing but shale to a depth of 2,000 feet. In drilling, the sandy beds are distinguished from the shales by their greater hardness, by the more rapid wear of the tools (the driller's chief criterion), and by the smaller amount of suspended matter in the water of the bailer. The washed-out samples commonly appear upon close examination as a collection of gritty shale granules, whose edges have been rounded under the drill. The better grades show an admixture of quartz grains, and exceptional beds are pure sand.

"Streaks" and "shells" are other terms used to indicate more than usual hardness at certain horizons. In the outcrops of these shales may frequently be detected hard beds a few inches or even several feet in thickness. They are either very calcareous or stained with iron oxide, or both, and owe their superior hardness to concentration of these substances. Such induration may affect the entire bed equally or may be concentrated into ellipsoidal concretions, which may be more or less separated, so that there are all gradations between the continuous hard plate and the isolated concretions. The word "shell" is suggestive of the concretions, as the word "streak" is of the plates, but in the reports the two words may be taken to be synonymous and alike indefinite. The comminuted fragments of these hard masses are not easily suspended in the water of the bailer, and probably for this reason, as well as on account of their superior hardness, are not infrequently reported as sand. On the other hand many of the so-called hard streaks are siliceous. The reports of "lime rock" are probably sometimes to be traced to the same occurrences, though, as seen on page 31, there are some true limestone beds in the Pierre.

OIL-BEARING STRATA.

The beds from which the oil is obtained are the highly variable sands or sandstones, described above as varying between clay shale and silica sand. Such beds may be met with at any depth, but there is no depth at which such rock is certain to be found. Reports might indicate that it is slightly more abundant at a depth approaching 2,000 feet, but this may be due to the sharper lookout for sand as the well gets deeper. Not all of these strata contain oil or gas; some of the most porous sands give no indication of either.

While the thickness of such beds may be anything up to 100 feet

or more, oil or gas may be obtained from only a part of their thickness. Such strata are plainly not so homogeneous as would appear from the bailings and, except locally, are far from being porous sandstones. Except in an oil well they would probably not be called sands at all. It is not uncommon to drill many feet into such strata and then strike a showing of oil or gas with no attendant change in the texture of the rock that can be detected in the bailings.

These small reservoirs of oil or gas seem mutually independent, being separated by the impervious shales. This isolation is well illustrated by the occurrence of deep veins of water in some wells and the absence of water from near-by sands in the same well or in adjacent wells. This mutual isolation of the several pockets is not accompanied by any great diversity in the character of the oils. With but few exceptions there is approximate uniformity, as shown by standard physical tests. Considering the striking uniformity of the great body of shales, this general likeness in the character of the oils is to be expected. Thus far there is but one authenticated instance in which the pumping of a new well has influenced the production of an older well. In this case the two wells are less than 200 feet apart. Curiously enough, these two wells found oil at depths differing almost 500 feet.

SHOOTING OF WELLS.

All but one of the wells which were pumped previous to the close of 1902 were shot. In 1903 this practice was less general. The amount of nitroglycerin used in these shots has varied from 10 to 140 quarts. Dynamite charges have been as large as 500 pounds, 70 per cent nitroglycerin. The effects of these shots have not been uniformly favorable. The beneficial effects in a few of the best wells have doubtless been responsible for most of the later attempts. More recently a number of wells have begun pumping without being shot. The fact that the flow of some wells has decreased since the shooting will lead to greater caution, and it is to be hoped that it will lead to a more careful study of the nature and thicknesses of the strata passed through.

The beneficial or harmful effects of a shot must depend largely upon the texture of the stratum yielding the oil, for it seems to be true that some shales are compacted rather than shattered by the explosion. Supposably for this reason, shooting is not practiced in the Florence field, which, of all the older oil districts, the Boulder field most resembles. Owing to the difference in texture of the various beds yielding oil in the Boulder field, it is but reasonable to expect that the same shot which would prove beneficial to one well

would be ruinous to another. On this account, if on no other, the texture and composition of the oil strata should be carefully studied by methods far more discriminating than the superficial ones first used in this field. It is but just to the companies and contractors now remaining on the ground to say that there has been much improvement in the character of well records.

A second reason for injurious effects from shooting lies in uncertainty about the exact depth of the sand which it is intended to shatter. Measurements of depths by steel tape are now becoming more common. In most of the earlier wells the depths of all formations are known only by cable measurement. It is not uncommon that the stated depths of important sands are thus liable to errors of 25 to 50 feet.

The possible injuries from a shot at the wrong place may be readily seen from the following consideration. If a porous rock is saturated with oil under pressure and is pierced by the drill, the oil is pressed upward in the hole solely because it has no outlet in any other direction, being surrounded (as in this field), or at least overlain, by impervious rocks. If this well is shot in such a way as to rupture the impervious rocks that surround the oil sand, the oil may leave the sand by other openings besides the well and may thus be dissipated in other porous beds and the well may be ruined.

Such an injurious effect may be produced even by shooting at the proper depth if the charge employed be too heavy. In one instance a well was shot at 740 feet with 500 pounds of dynamite, 60 per cent nitroglycerin. The formation above the sand was a uniform dense shale. A good quality of sandstone was blown from the hole in large chunks, one of which weighed 14 pounds. The shale was ruptured to the surface. Open cracks an inch or more wide extended for some rods from the well. It may be presumed that cracks also reached a considerable depth below the sand which was to be shattered. The well, of course, yielded no oil.

It can not be too carefully borne in mind that the one object in shooting is to shatter the rock which carries the oil and that only. With this object in view, it is plain that intelligent and discriminating shooting must depend upon the answers to the following questions: Is the oil stratum of such a texture that it will be shattered rather than compacted? What is the exact depth of its top (and bottom if drilled through)? How much of a shot will the overlying rocks bear without giving other outlets to the oil? This last question is one of great importance in this field. It is needless to say that such questions can be answered only by a carefully kept log and close study of samples, not only of oil sands but of all strata, in order to properly forecast their behavior under the influence of a shot.

Wells which were shot previous to June, 1903.

Name.	Charge of nitroglycerin.	Depth of shot, in feet.	Effect.
	Quarts.		
McKenzie	140	2,530–2,587	No change.
Savanna No. 1	40	.....	Abandoned after shot.
Savanna No. 2	100	2,115	Intended to shoot at 2,100; abandoned after shot.
Savanna No. 3	50	1,579–1,600	Reduced production from 10 barrels to 5 barrels.
Savanna No. 3 (second shot).	100	1,579–1,600	Produced about 7 barrels after second shot.
Otero No. 1	60	1,649–1,673	Not pumped before; a good producer.
Otero No. 2	10	1,724–1,761	Not pumped.
Otero No. 2 (second shot).	60	1,724–1,761	Little oil before; not pumped; a fair producer afterwards.
Otero No. 3	[a] 10	1,600–1,900	Shot four times; little oil.
Otero No. 3 (fifth shot).	60	1,807–1,837	Produced 3 or 4 barrels.
Bradford No. 1	100	.....	Produced 4 or 5 barrels.
Bradford No. 2	30	1,650	Went on drilling.
Bradford No. 2 (second shot).	15	1,720	Very small producer.
Boulder Illuminating.	100	.....	Not pumped before; a very small producer.
Crawford	100	2,682–2,734	Fair well before; ruined.
Boulder Valley	80	2,021	Increased production from 6 barrels to 15 barrels.
Hayden No. 1	.....	2,005	Shot with 500 pounds dynamite, 70 per cent; no effect.
Do	80	Same depth.	Never pumped.
Central	100	2,600	A little oil: soon abandoned.
Two-ten	120	2,111–2,141	Not pumped before; small producer afterwards.
Hayden No. 2	40	2,135	Never pumped.
Anderson	40	2,670	Do.
Wisconsin No. 2	40	2,035	Small producer; drilled deeper and abandoned.
Boulder-Peoria	80	.....	Never pumped.
Independence	60	1,100	Do.
Boulder-Valmont No. 2.	60	1,650	Drilled deeper.
Boulder-Valmont No. 2 (second shot).	60	1,947	A fair producer.
Dismuke	60	2,064	Not pumped before; a small producer afterwards.

[a] For each shot.

Wells which were shot previous to June, 1903—Continued.

Name.	Charge of nitroglycerin.	Depth of shot, in feet.	Effect.
	Quarts.		
Buffalo	40	1,600	No oil; did not affect gas production.
Republic No. 1	24	965	Little or no change.
Republic No. 3			Shot with 100 pounds dynamite; no change; dry hole.
North Bend		740	Shot with 500 pounds dynamite, 60 per cent; hole ruined.

STRUCTURE OF THE OIL FIELD.

From all observations previous to the preliminary report made by the writer in January, 1903,[a] there appeared to be no law governing the distribution of oil in the Pierre shales. Small bodies of oil have been found in various parts of Colorado and neighboring States, but their structural relations, so far as known, afforded only vague explanations of their presence, and left the prospector with the impression that oil might or might not be found at almost any place in the Pierre.

The want of any known evidence of anticlinal arches suggested the inference that such structures were unnecessary to form receptacles for oil and gas in so dense a rock as the Pierre shales. The idea of some connection with folds was, however, not given up, and renewed efforts were made to induce companies and drillers to preserve samples and careful records, with a view to determining the exact position of the strata. During the summer of 1903 a detailed structural study was made of an area of 150 square miles, of which the oil field occupies the center.

It is a noteworthy fact that, with the exception of two very small producers, all the wells which have thus far produced oil are in a very narrow north-south belt. It is now known that this belt follows a monoclinal fold, the wells being near the top, and therefore in similar structural position to those of Ohio described by Orton as occurring on "arrested anticlines." The two very small producing wells, referred to above as located outside the narrow belt, are the Two-ten, one-half mile east, and the Boulder Illuminating, 1 mile east. It will be seen below (p. 92) that these wells occupy very significant positions with respect to another fold.

The monocline on which the wells are located is almost in line with an incipient échelon fold to the north-northwest, which affects the

[a] The Boulder, Colo., oil field: Bull. U. S. Geol. Survey No. 213, 1903, p. 322.

foothill belt after the characteristic manner of such folds in this region. (See p. 43; also map, Pl. II.) For the present purpose it is best seen in the prominent offset in the outcropping edge of the Hygiene sandstone in sec. 6. The axis of this fold points east of south. In the outcrop of the same sandstone, but 5 miles farther northeast, a well-developed fold of similar character branches off, with an axis trending almost due south. Both these folds are described below. The monocline which determines the present line of producing wells is the southward continuation of the western and smaller one of the two flexures, but it is affected both in degree of flexure and in the direction of its axis by the stronger fold to the east.

It may be confidently affirmed that whatever may be the nature of the occurrence of oils elsewhere in the Pierre, there is nothing thus far known in the field at Boulder to offer encouragement to prospectors, except in intimate relation with folds. The essential features of this particular flexure should, then, be determined with care. Such a study may afford a basis for inference as to the probable oil-bearing or barren character of other similar structures occurring throughout a distance of 50 miles along the front of the range.

The form and location of these folds are best made clear by tracing the outcrop of the Hygiene sandstone (see p. 31), which made possible the discovery of the folds. Near Boulder the stratum is thin and weak and is separated from the Niobrara on the west by not more than 1,000 feet of shales. Seven miles north of Boulder it is 250 feet thick, and the Pierre shales below it have thickened to nearly 3,000 feet. As the dip has also greatly decreased within the same space, the sandstone outcrop has been carried nearly 2 miles to the east.

Stated more definitely, the outcrop forms a prominent cuesta (a ridge of abrupt scarp slope and long, gentle dip slope) running from the southwest corner to the northeast corner of sec. 6, T. 1 N., R. 70 W. This northeastward strike in sec. 6—an exception to the prevailing trend, which is almost north—is the surface expression of a mild tendency to échelon folding. It belongs to the same flexure as the monocline of the oil field, and its more prominent northwestward extension has been described on page 44. From the northeast corner of sec. 6 the outcrop extends north by east through the west side of sec. 32, T. 2 N. For nearly a mile north of this, in the vicinity of Lefthand Creek, the ridge is lost, but it reappears in the west half of sec. 20, running almost north. On the north side of this section the outcrop disappears under Table Mesa. If the mesa is crossed in a northeasterly direction, its northern side is reached in the middle of sec. 9. At this point the sharp crags of this sandstone are seen, forming a bold, bare ridge running far away to the northeast (N. 27° E.).

If the mantle rock were removed from the mesa it is believed that the outcropping sandstone ledge would be seen to describe a great loop (see map, Pl. II) instead of cutting straight across from the point where it disappears under the southwest side to where it reappears on the northeast. The reasons for assuming such a structure will appear in a description of the outcrops.

As noted above, the strike for the last mile or two on the southwest side of Table Mesa is nearly north. Similarly on the northeast side, the ledge which approaches the plateau with a strike of S. 27° W. turns, just before its disappearance, to a direction differing only 8° from due south. The two outcrops, therefore, on the northeast and southwest sides would, if prolonged in straight lines, miss each other by about a mile.

There is a second outcropping ledge of sandstone on the south side of Table Mesa, a little more than a mile east of the one mentioned above, and about one-half mile west of Haystack Mountain. The sandstone of this eastern outcrop also forms a low ridge, and is to all appearances identical with that of the more westerly exposure. It shows the same succession of beds—a strong ledge of sandstone and a second horizon, a few hundred feet higher, marked by great calcareous concretions. (See p. 32.) The strike here is N. 35° W., and the dip is 10° to the northeast.

This low ridge abuts, as do those of the other outcrops, against the steep mesa scarp. It is believed that this line of outcrop is directly continuous with that which approaches Table Mesa from the northeast; that it represents the eastern limb of an anticlinal fold whose crest has been eroded away; that if the soil cover could be removed and the edge of the Hygiene sandstone everywhere exposed it would be found again dipping west on the western limb of this anticline a quarter to a half mile west of the eastern exposure; that the loop would be seen as represented in fig. 9, the outcrop crossing Table Mesa with a southerly trend from the middle of sec. 9, passing in a southeasterly course past Haystack Mountain, looping perhaps a mile to the south, then turning back to the north for 3 miles or more, then turning sharply around once more to the south along the course first described.

The structure here described is inferred mainly from dips, all of which within the area concerned agree with the features described. Although the Hygiene sandstone shows no good outcrop on the western limb of the anticline, westward dips as high as 18° are plainly seen within the sandy shales on the south side of Lefthand Creek near the line between secs. 28 and 29. At the north end of the canoe-shaped synclinal trough southward dips are found, according

perfectly with the assumed structure. These may be seen along the high, level ditch skirting the northwest side of Table Mesa.[a]

Such an anticlinal fold as the one just described must die out gradually at the end. (See fig. 10.) If the axis be traced southward, the dip of the western limb should become less and less steep. At a certain point the westward dip will become zero; there will be a structural bench, as it were, interrupting the general eastward dip. This bench will be horizontal, except for a southward

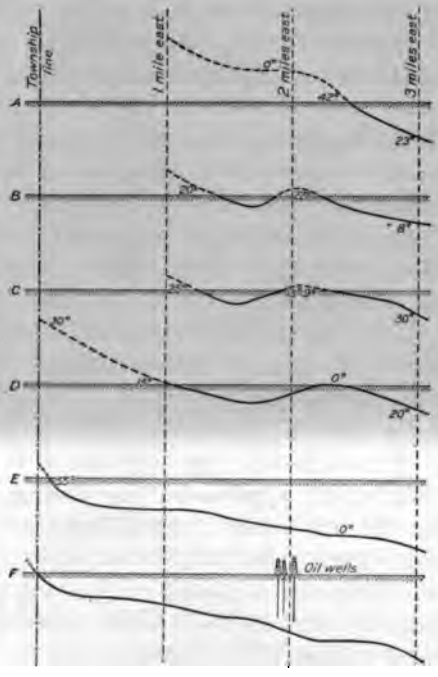

FIG. 10.—Cross sections showing the folding of the Hygiene sandstone. The straight horizontal lines represent the surface of the ground. The solid curve indicates the present position of the stratum, and the dotted curve indicates the position of the stratum before erosion. A, 10 miles north of the fortieth parallel, which is 1 mile south of Boulder; B, 9 miles north; C, 8 miles north; D, 6½ miles north; E, 5 miles north; F, 4 miles north.

inclination. Still farther south the whole will again dip toward the east, but in line with the axis of the anticline the dip will be smaller than either east or west of that line.

In the north side of sec. 9, T. 1 N., northwest of the Beasley reservoir, the only dip is one to the south, as is made apparent on the map

[a] This structure was first described by the writer in a paper entitled Structure of the Boulder oil field: Bull. U. S. Geol. Survey No. 225, 1904, p. 383. Since that publication and since the above paragraphs were written Messrs. S. F. Rathvon and William Rathvon, oil operators, have had eight holes dug to ascertain the dip of the shales in sec. 33, T. 2 N., R. 70 W., and secs. 4 and 9, T. 1 N., and to verify the structure as described above. The results have fully confirmed the statements made here.

by the outcropping of two arenaceous beds, the lines of outcrop having an east-west direction. This is on the axis of the larger fold. At this place the axes of the two folds (see p. 88) are in proximity, and the eastern and stronger fold uplifts the east side of the feebler western fold, making a horizontal bench out of what would otherwise be only a partial flattening of the general eastward dip. The result is seen on a line passing south through secs. 8, 17, and 20, along which the shales have no eastward dip. This belt is, however, narrow—a small fraction of a mile—and in short distances both east and west of it decided eastward dips appear.

Immediately east of this bench, perhaps on an average one-fourth of a mile, the producing wells are found. Their linear arrangement is all the more striking if the line be extended south to include the Buffalo gas well in the southeast corner of sec. 29. The position of the oil-producing strip is in exact accord with that of oil-producing belts of Ohio, where the conditions of occurrence have been made so well known by the very complete discussion of Orton.[a] The possible finding of other pools remote from such a structure need not be discussed here. They may or may not be found in structures differing from the one to which they are here related. It can only be said that the example of the already developed portion of this field offers no warrant for prospecting where these structural features are absent.

It may safely be assumed that the one significant feature in the structure of the oil field is the decided arrest of the general eastward dip. The peculiar relation of the two folds whose effects at this place unite to produce the result is not in itself taken to be significant, except in so far as it explains the occurrence or location of the one valuable feature. Further, it must not be assumed that this or any similar flexure will necessarily be oil-bearing throughout its whole length. Even very small transverse folds affecting the axis are sufficient to break up the deposit into so-called "pools." The intermittence of good oil territory along the line thus far developed, from secs. 8 and 9 on the north to the Buffalo gas well on the south, is already known. It can not therefore be assumed that one or two dry holes indicate that a line marked by the above-described structure is entirely barren.

SUGGESTIONS AS TO FURTHER DEVELOPMENT.

If, then, the promise of future developments in this oil field be limited to a relationship with folds, it is highly important to exam-

[a] The Trenton limestone as a source of petroleum and inflammable gas: Eighth Ann. Rept. U. S. Geol. Survey, pt. 2, 1889.

ine similar occurrences beyond the limits already developed. In the discussion, however, it must always be taken into account that the beds capable of containing deposits are small and of uncertain lateral extent. At the outset the further extension of the immediate group of productive wells demands attention. The axis of the fainter of the two folds, whose combined effects produce the monocline in and south of sec. 8, runs northward from the present developed field, but the very few exposures along this northern portion have not shown dips less than 6° or 7°, and therefore no close approach to the structure described above as occurring farther south, in the vicinity of the successful wells.

The stronger fold to the east completely neutralizes the general eastward dip as far south as sec. 4, while farther north it has a westward-dipping limb. The axis of this fold runs north by a little west through sec. 4, T. 1 N., R. 70 W., and secs. 33 and 28 of T. 2 N. The axis of this fold has not been tested by the drill. At its southern extremity, however, where the strata begin to dip strongly southward (10° or 15°), is the Two-ten well, and one-half mile farther east is the Boulder Illuminating. Both of these wells are small producers (about 2 barrels a day from each well), but the finding of oil, even in small quantities, in this relation to the fold is significant. From a structural standpoint it may be expected that if larger quantities of oil are present they will be found nearer the axis of this fold rather than farther away.

Sheet No. XII of Hayden's Atlas of Colorado shows with considerable detail a series of large échelon folds, but those described above are, in general, too small to appear on that map. The salient curve in the Dakota, however, shown on the Hayden map north of Lefthand Creek, must be correlated with the long loop in the Hygiene sandstone described above. If this latter formation were drawn on the Hayden map, the loop in question would be three-fourths of an inch long. A fair idea of the relative sizes of such folds may be had by comparing the effects of each on the same formation, as, for example, on the Dakota.

The question of stores of oil in the larger folds naturally suggests itself, in view of the known relation of oil to the smaller. It is to be remembered, however, that in the Appalachian region it is not the great anticlines which have conserved the hydrocarbons. Here, as there, the greater deformations may prove to have made poor reservoirs, probably by the opening of cracks. Nor, indeed, has it yet been shown that the larger of the small folds in the Boulder field is an oil reservoir. If the future proves otherwise, there will be a strong presumption in favor of restricting the search for oil to folds of the smaller order. If the large folds shown on the Hayden map

are to prove oil-bearing, it will probably be in their remote ends, where the fold is dying out on the plains.

A condition of this nature has been put to the test in one instance. A fine fold of this kind, north and east of Lyons, flattens out in the vicinity of Hygiene (about 12 miles north and 5 miles east from Boulder). Here, in a line transverse to the axis, three wells were drilled to depths approximating 3,000 feet. They were not without showings of oil, but a better showing was obtained 4 miles farther down its axis to the southeast, where the fold has flattened greatly and was probably never considered a factor. Oil from a depth of about 600 feet has also accumulated in an abandoned water well, a mile north of Hygiene. This is also on or near the axis of the fold.

If the larger folds fail to yield oil, the one remaining hope (probably more promising from the start) lies in the smaller folds. For reasons given above, these, in so far as they affect the Pierre shales, are betrayed only by the most obscure outcrops. Yet it is in this formation, at a distance of a few miles from the harder rocks of the foothills, that folds must be found if they are to serve as guides in prospecting for oil.

Herein lies the large significance of the similar though often very small flexures which affect the stronger and well-exposed strata of the foothills from Morrison to Niobrara, inclusive. In these stronger rocks they may be very small, the looping back generally being less than a quarter of a mile; but the same stress will be found to have produced larger results in the weaker Pierre. Therefore, if the Pierre shales are to be prospected in this region of échelon folding, much time will be saved by making a preliminary examination of the stronger strata. Where the Hygiene sandstone is exposed, it is the natural index of structure and the best. Where it does not outcrop, the basal Niobrara limestone is the nearest criterion.

In these suggestions no account is taken of the possibility of folds running strictly parallel to the foothill outcrops. This is of course possible, especially south of Boulder, where the échelon type is not prevalent. The lines of procedure suggested above are only those which have been derived from the known structure of the already developed field. They are not intended to exclude consideration of structures not yet exemplified.

The Maxwell gas well, less than 2 miles north of Boulder and a little more than half a mile from the Pierre-Niobrara contact, may seem an exception to all that has been said above regarding the location of oil and, by inference, of the closely associated gas. It might therefore be thought of as putting the generalization to a severe test. Near-by outcrops are too few and unsatisfactory to fix the structure with any definiteness, but it is a remarkable fact that this well lies

south-southeast from an incipient échelon fold which affects the boundaries of all outcrops from the Lykins to the Benton. (See p. 43.) The axis of this fold would seem to pass a little west of the Maxwell well.

SOURCES OF THE OIL.

The strata containing the original substances from which the oil of the Boulder field has been derived are not determined with exactness. Much of the Pierre is black with disseminated carbonaceous matter. The Niobrara below is bituminous, yielding a strong odor, especially from its more fossiliferous beds. The same is true of the Benton, whose shales are characteristically dark, and whose bituminous odor is at least as well marked as that of the Niobrara. The Dakota bears oil in Wyoming, and an asphaltic substance oozes from its cracks at various places from Wyoming to southwestern Colorado. Even the Morrison beds contain some oil, as seen near the Florence field.

The strata thus enumerated have a combined thickness of from 5,000 to 6,000 feet below the horizon of the lowest oil reached in the Boulder field. The Benton and Niobrara are doubtless richer in organic matter than any higher strata and surely far richer than anything below. While these considerations are favorable to the beds below the Pierre as the ultimate sources of the oil, others favor a source not far from the horizon at which the oil is found. Neither hypothesis is established and neither can yet be abandoned.

The great density of the Pierre shales must make them a serious barrier to the passage of any form of matter. It is significant that the same dense shale which forms the so-called "cap rock," and is therefore considered impervious to oil or gas, also underlies the oil, and must therefore have been traversed by the hydrocarbons for thousands of feet if the ultimate source of these substances was in the Benton and Niobrara. It is also noteworthy that some of the purest white friable silica sand found in deep wells has contained no oil. Such sands must have been quickly discovered by the rising hydrocarbons working their way upward from great depths through the scanty pores of the shale. Both the general density of the shales and the absence of the oil from certain friable sands favor a hypothesis which locates the original source of the oil at horizons not very far from those at which it is now found. In this case it is safe to say that the tilting of the beds has given opportunity for the segregation of their fluids according to their several specific gravities. Theory would require that the oil should be found just about where the present wells are located; that is, on the slope below the horizontal bench. The summit of the monoclinal slope, or edge of the structural

terrace, should be the approximate western limit of gas, or of oil, if there be little gas present. This is because fluids lighter than water, after rising through an inclined porous stratum to this line, could find no higher place to go.

A similar segregation might occur in beds whose dips are not interrupted by a horizontal bench. If oil, in mounting to higher levels through such porous beds, finds them gradually changed to dense shales, there must result an accumulation along the upper margin of the porous portion, regardless of folds and interrupted dips. It is not improbable that small accumulations of this kind exist in the Pierre shales and may in the future be found. The chance that such may exist is independent of the original source of the hydrocarbons. It matters little whether this was near the horizon of the oil-bearing strata or thousands of feet below.

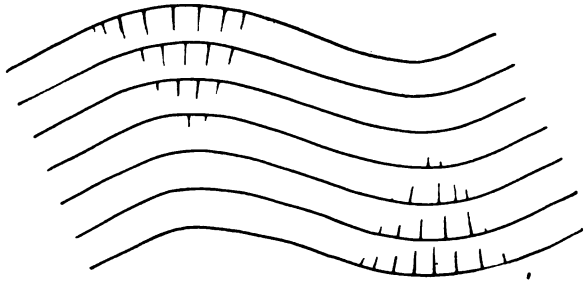

FIG. 11.—Hypothetical cracking in the formation of the oil-field monocline.

The suggestion of a deep source for the original constituents of the oil, based on the bituminous character of the Benton and Niobrara beds, is so strong that any plausible explanation of its rise through the Pierre shales deserves consideration. While in general highly dense, it is not certain that the Pierre shales directly below the known oil deposits are unfractured. If affected by fracture they may not be so impervious as would be inferred from a study of samples. The folding along this belt may have had more significance than the making of suitable closed reservoirs in which to hold the oil. At the foot of such a monoclinal offset as has been described, the lower strata might well be expected to be stretched and those above compressed. (See fig. 11.) At the top of the monocline, the reverse is true; the upper beds should be stretched and those below compressed. If such folding, therefore, is to result in greater permeability of the lower beds along any belt, it must be along the

foot of the monoclinal slope. From all observations in this field, this tendency to fissuring in the deeper beds might well be the chief significance of the monocline. It has been pointed out above that the axis of the oil-producing belt so far as explored is a full quarter of a mile east of the north-south line along which the shales are horizontal. The dip of the shales through which the producing wells are drilled approaches 20°. Assuming the folds of the lower strata to be similar to those above, and remembering that no reservoirs of gas have been found, which might be expected to crowd the oil down the slope, this situation of the oil deposits does not favor the analogy of the anticlinal reservoir. It seems to suggest that the foot of the monoclinal slope may be quite as important in relation to the accumulation of oil as is its top.

There are here, therefore, two possible ways in which folding may have affected these oil deposits: (1) It may have provided suitably constructed reservoirs; (2) it may have made the deep rocks sufficiently permeable to allow the ascent of hydrocarbons from the lower formations whose constitution makes them the most plausible sources. If the deeper origin be assigned to the oil, then the second consideration is more urgent in this field than the first, though the two are quite consistent. The second consideration provides for communication (otherwise seemingly impossible) with the most bituminous beds of the region. It also localizes the upward movement of the hydrocarbons along lines of fracture, thus accounting for the absence of oil and gas in some of the most porous sands. It also harmonizes well with the situation of oils far down the monoclinal slope. Finally, such a structure in a mass of shales containing occasional sandy beds would result in accumulation at very diverse depths. Fractures leading up from below would here strike and there miss sands of limited lateral extent, just as the wells reaching down from the surface have done.

The stretching and possible fracture of the deeper beds at the foot of a monoclinal slope are, of course, not open to observation. The corresponding process in the upper beds at the top of the slope has left the marks which were to be expected in this field. A considerable amount of fracturing is evidenced by calcite vein filling. In the SE. ¼ sec. 6, T. 1 N., R. 70 W., where there is the incipient échelon fold that has been described (map, Pl. II), the north side of the mesa shows broad exposures of the bare shales. The weathering and erosion of these has left the surface strewn with chunks of calcite which occupied the crevices of the shale. These veins are often several inches wide. Similar evidence is seen just west of the oil wells, where the horizontal position of the shales gives way to the eastward dip.

It is not intended to suggest that the lower beds at the foot of the monoclinal slope could be affected by open fissures. The necessary depth to which permeability, resulting from deformation, must be extended in order to reach the Niobrara and Benton is even now well above half a mile, and it may have been one or two thousand feet more at the time the folding took place (assuming subsequent denudation to that amount). At such a depth it is not to be expected that crevices in shale will open wide; indeed, the plausibility of the entire supposition here sketched depends upon the possibility of any fracture at all. However, inasmuch as the shale, when perfectly fresh, is a fairly strong rock, it seems at least probable that deformation within the zone concerned would be by fracture rather than by flowage. Still the connection between oil accumulation and permeability caused by folding can not yet be affirmed. Some questions remain to be answered before this supposition can be made a working hypothesis.

PHYSICAL PROPERTIES.

In physical tests the products of the different wells show a noteworthy resemblance, despite the diverse depths from which they are derived. There are minor differences in color, but in general the oil is a light amber and has a paraffin base and an agreeable odor. Gravity tests range from 42° to 44.6° Beaumé. In all flash tests reported the oil has flashed below 60° F., and the exact temperature of the point was therefore not recorded. The proportions of the more valuable products of refinement, notably that of kerosene, are very large. The current price of the crude oil, $1.10 per barrel, is the best indication of its quality from a commercial point of view. It is said by Oliphant to be the best oil west of Mississippi River.[a]

PRODUCTION OF OIL AND GAS.

As stated above (p. 77), there are nearly 70 wells in the productive area, though this number includes some very shallow holes. Twenty-eight have pumped oil at some time. Twelve of the 28 were abandoned before October, 1904, and a few others were not at that time pumped with any regularity.

The oil production amounted to 11,000 barrels in 1902 and 39,000 barrels in 1903. While a very substantial gain is thus indicated when the output is stated by years, the monthly production at the close of 1903 was smaller than at the beginning of the year. The average daily production for 1904 did not exceed 70 barrels.

[a] Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1904, p. 562.

One gas well, the Buffalo, in the southeast corner of sec. 29, and therefore in the same north-south line with the oil wells, but farther south, has yielded considerable quantities of gas for several years. The gas is piped to Boulder and was at first used in connection with the manufactured gas. Since September, 1903, no gas has been manufactured, and the quantity of gas used from the well has been gradually increased. The rate of consumption has at times been nearly 3,000,000 feet per month. It is probable that the present rate of consumption could not with safety be greatly increased, but no diminution of the capacity of the well has yet been observed. Its quality is very satisfactory.

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Bulletin No. 266 Series C, Systematic Geology and Paleontology, 73

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

PALEONTOLOGY

OF THE

MALONE JURASSIC FORMATION OF TEXAS

BY

FRANCIS WHITTEMORE CRAGIN

WITH

STRATIGRAPHIC NOTES ON MALONE MOUNTAIN AND THE SURROUNDING REGION NEAR SIERRA BLANCA, TEXAS

BY

T. W. STANTON

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., February 4, 1903.

SIR: I transmit herewith, for publication as a bulletin of the Survey, a manuscript entitled "Paleontology of the Malone Jurassic Formation of Texas," by Francis Whittemore Cragin. Professor Cragin prepared a large part of this paper in 1899, beginning the work while he was a graduate student in Johns Hopkins University, Baltimore, and continuing it here under my supervision in accordance with authority obtained from you at the time. I have inserted a sketch of the stratigraphy of the region and have prepared the accompanying map, using data furnished by Professor Cragin for the portion of the region referred to in his text.

I may add that Professor Cragin's collection of Malone fossils is now the property of the United States National Museum.

Very respectfully,

T. W. STANTON, *Paleontologist.*

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

PALEONTOLOGY OF THE MALONE JURASSIC FORMATION OF TEXAS.

By F. W. Cragin.

INTRODUCTION.

SCOPE OF INVESTIGATION.

This paper embodies the paleontological and some geological results of recent studies in the Jurassic of El Paso County, Tex. It is in part the outgrowth of one of briefer scope, prepared in 1897–98 from collections and data obtained by me in a reconnaissance made in 1897, and supplemented by some of the results of the earlier work of Messrs. Taff, Wyschetzki, and Goodell, as explained below. In its present form it includes also the study of two collections made by Dr. T. W. Stanton, of the United States Geological Survey, as noted more particularly elsewhere herein.

GEOGRAPHY OF THE REGION.

In El Paso County, a few miles north of the Rio Grande and 75 to 80 miles southeast of El Paso, is a narrow ridge known as Malone Mountain. Its trend is nearly north-northwest and south-southeast, and is nearly continuous with that of the northwestern end of the Quitman Mountains, from which it is separated by an interval of less than a mile. At the eastern base of the mountain, near its northern end, on the joint line of the Southern Pacific and Texas Pacific railways is the flag station of Malone, which has an elevation of 4,262 feet above sea level.[a] Also on this line of railway, and between 2 and 3 miles west of the north end of Malone Mountain, is Finlay station. As shown by the Fort Hancock sheet of the Topographic Atlas of the United States, in preparation by the United States Geological Survey, the mountain rises to somewhere over 5,050 feet above sea level, and so has a relative altitude of about 800 feet. On either side of the mountain ridge are hills that are geologically related to the mountain.

[a] Gannett, Henry, Dictionary of altitudes in the United States, third edition: Bull. U. S. Geol. Survey No. 160, 1899.

HISTORY OF GEOLOGICAL STUDIES.

The geological observations made along this part of the Rio Grande Valley in the fifties by the Mexican Boundary and Pacific Railway surveys were but cursory, and did not specifically include the Malone district, and the first serious geological study within the district was made in 1890 by the Geological Survey of Texas, under Mr. E. T. Dumble. In that year Mr. J. A. Taff, then attached to Mr. W. H. von Streeruwitz's Trans-Pecos division of that survey, studied Malone Mountain, and Mr. Ralph Wyschetzki, of the same division, collected a few fossils from the hills northeast of it. In the second annual report of the same survey, issued in 1891, Mr. Taff published and discussed a section of Malone Mountain and described, with scant allusion to its paleontology, an essential part of the Malone formation, consisting of limestone, gypsum, and flagstone of Malone Mountain, which he called the "Malone beds." He thus virtually recognized the formation, his name for which, as the earliest proposed for it, is here retained; but he erred in placing it in the Washita Cretaceous division together with his Etholen and Yucca beds, which are typically seen in a part of the Etholen Knobs and Yucca Mesa, and are of Glen Rose age. Mr. Taff also correlated the sandstone and oyster-shell breccia of the Etholen Knobs with the Malone formation, but these, like the Etholen breccia-conglomerates and the Yucca beds, belong to the Glen Rose alternating beds.

In 1893 I described[a] the better part of a small collection of fossils which Mr. Wyschetzki had obtained from the hills northeast of Malone Mountain. Disregarding for the moment a strong suspicion that these fossils were Jurassic, I described them as Cretaceous, since the time and material then available were too limited for a conclusive study, and since it was thought that the small Malone fauna then known had one species in common with the Cretaceous, in *Trigonia taffii*, which occurred with undoubted Cretaceous fossils on Bluff Mesa and was supposed to have been found in the Malone district also.[b] But I resolved to take up the question at the first opportunity that should offer.

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[a] A contribution to the invertebrate paleontology of the Texas Cretaceous: Fourth Ann. Rept. Geol. Survey Texas, pt. 2, pp. i–lv, 139–246, and Pls. XXIV–XLVI.

[b] The material thus treated included six new species, which were described under the following names: *Anatina tosta, Cucullæa transpecosensis, Cyprina streeruwitzii, Trigonia vyschetzkii, Trigonia taffii,* and *Venus malonensis.* It was afterwards found that *Trigonia taffii* does not occur at all in the Malone formation, but is a fossil of the Glen Rose alternating beds, to which Bluff Mesa belongs. The type material of *Trigonia taffii* was described (loc. cit., p. 214) as having come in part from Bluff Mesa and in part from the locality of *Trigonia vyschetzkii,* east of Malone. It is now, however, practically certain that the nearly complete valve from Bluff Mesa alone represented *Trigonia taffii,* and that all of the fragmental material which was supposed to belong to this species, and which was from the Malone locality, belonged—as part of it which I recently had opportunity of reexamining certainly does—to *T. vyschetzkii.* All of the very diligent collecting done at the Malone locality by Doctor Stanton and myself, while showing the occurrence of T.

No opportunity for further investigation of the Malone fauna was presented until 1895. In March of that year the late Mr. Robert W. Goodell, assisted by his father, Mr. R. R. Goodell, made a journey to Guaymas, Mexico, to obtain recent marine invertebrates from some rich collecting grounds on which I had worked in the winter of 1882–83. In returning, he very kindly undertook to visit Sierra Blanca and Quitman mountains, Bluff and other mesas, and the hills north to east of Malone, to seek further evidence concerning the age of the rocks that had yielded the Wyschetzki collection. From the Sierra Blanca Mountains and several other of the elevations visited, which did not include Malone Mountain, the Messrs. Goodell brought back a large number of fossils, all of which were of the Comanche series save those from the hills a mile and a half east of Malone station. Those from the latter locality included, besides several of the species obtained there by Mr. Wyschetzki in 1890, some specimens which the writer recognized as specifically identical with the Mexican Jurassic fossil, *Pleuromya inconstans* Castillo and Aguilera, and one example of an undescribed Trigonia of the Jurassic section Undulatæ. A restudy of *Trigonia vyschetzkii*, of which the Messrs. Goodell had obtained new material, led me to the conclusion that the affinities of that fossil also were Jurassic rather than Cretaceous. In 1896–97, therefore, I prepared a brief paper on the "Discovery of marine Jurassic rocks in southwestern Texas," assigning to the Malone formation a stratigraphic place somewhat different from that given to the original "Malone beds" of Mr. Taff, and announcing its Jurassic age. This article, which included, from the field notes of Mr. Robert W. Goodell, the latter's section of the hills northeast of Malone station, was published in the Journal of Geology, Volume V, pages 813–820.

It was noted in this article that a comparison of the observations of Mr. Goodell with those of Mr. Taff seemed to show petrographical grounds for a formational correlation of the hills northeast of Malone station with the Malone beds of Malone Mountain. Such correlation, for a part of these hills and a part of the mountain, was confirmed paleontologically by me in August, 1897, when I visited El

vyschetzkii in profusion, has failed to yield a single fragment of the *T. taffi*. On the other hand the fauna with which *T. taffi* is associated was examined by Doctor Stanton and by me in 1897, both by a joint excursion to Bluff Mesa and by our independent examinations of the W. F. Cummins Red Bull Canyon collection in the museum of the Geological Survey of Texas, and was found to include, with some species hitherto undescribed, others of the Glen Rose Cretaceous.

In 1894 Mr. Cummins made a collection of fossils, including *Trigonia taffi*, near the southern end of the Quitman Mountains, labeling it "Mule Canyon." An excursion to Mule Canyon was made by Doctor Stanton and myself in 1897, but the fossiliferous rocks in its vicinity were found to contain Cretaceous fossils unlike those collected by Mr. Cummins. Further search by Doctor Stanton in 1898 resulted in his discovering the locality of the Cummins collection, which was found to be Red Bull Canyon, the designation, "Mule Canyon," having been used by Mr. Cummins on his labels through some inadvertence.

Paso County, Tex., and found that certain fossils were common to the locality a mile and a half east of Malone station and to the southeastern quarter of Malone Mountain, and in September of that year and in the summer of the year following, for the mountain in general and its western foothills, by Dr. T. W. Stanton, who found for these and the eastern foothills an essentially common fauna.

I arrived at Sierra Blanca station August 19, 1897, and remained till September 7, reconnoitering in several directions from that station as headquarters and giving the greater part of my time to the Malone district. I examined parts of the eastern slope of Malone Mountain, from which also I obtained a few fossils, and observed, from the southern part of the mountain crest, the general relations of the western foothills. But it was to the eastern hills, as including the locality that had yielded the interesting fossils to Mr. Wyschetzki and the Messrs. Goodell, that I gave chief attention; and from these hills I made a large collection of fossils. The western slope and foothills of the mountain I was unable to explore for lack of time.

On September 2 Doctor Stanton reached Sierra Blanca and joined me in exploring and collecting for a few days, both in Cretaceous localities and in the eastern part of the Malone district. Doctor Stanton remained in the field after my departure and carried reconnaissance further westward than I had, examining the western slope and foothills of Malone Mountain and making a section of the mountain. In the summer of 1898, with more time and better facilities at his disposal than had been available to either of us in 1897, Doctor Stanton returned to this part of Texas and made additional collections and a comprehensive examination of the Malone and contiguous territory. Later, with the consent of the Director of the United States Geological Survey, Doctor Stanton very generously turned over to me for study and description all of the marine fossils collected by him from the Malone formation in his two expeditions. Doctor Stanton's geological observations will be given by himself in another connection herewith.

The types collected in the Malone district by the Geological Survey of Texas in 1890 and described in the fourth annual report of that survey have in part been loaned to the United States Geological Survey by Doctor Dumble and used in preparing this paper. Most of the species thus early collected are represented by ampler material from later collections. The more important of the specimens of the Goodell Malone collection, which were given to me by Mr. Robert W. Goodell in 1897, and my Malone collection, made in the latter year, have recently become the property of the United States National Museum and, first studied in the summer of 1898, have been restudied *in connection with the* other material. The material on which these

paleontological studies are based therefore includes, with the exception of three or four mislaid specimens, all of the marine fossils that have hitherto been collected in Texas from rocks of the Malone formation.

GEOLOGY OF THE REGION.

All of the fossils described in this paper are from Malone Mountain and neighboring hills, and from within a few miles of the railway stations of Malone and Finlay. The greater number were obtained from east of the mountain, in the range of low hills which, in my article on "Discovery of marine Jurassic rocks in southwestern Texas," I called the Malone Hills.

Beginning about half a mile north of Malone station, and in part too low to be indicated by the contour lines, with 50-foot intervals, used in the general topographic map of this region, these hills extend, trending at first about eastward and later more southeasterly, as a practically continuous Jurassic outcrop through the Neocene, for a distance of a mile and a half. At a mile to nearly a mile and a half from the station they include a line of three connected hills (*C*, *D*, and *E*, on Pl. I, in order of distance from the station), which may be called the Trio. As best observed on the southeastern quarter of hill *E*, the Trio geological section comprises three natural subdivisions, the lower, middle, and upper of which respectively may be designated as Theta, Iota, and Kappa.

The Theta subdivision of this section consists chiefly of sandstone, with occasional courses of more or less sandy varying to relatively pure indurated limestone and some clay. The sandstone and clays are of a gray and yellowish-brown color, sometimes varying to purple and red. The purer of the limestone layers have a bluish-black color, weathering to gray or brown. Bedded and irregular seams of white cleavable calcite, sometimes several inches thick, here traverse the Theta in its upper part. The base of the Theta is not exposed.

A short distance southeast of hill *E* is a very low truncate mound (*F*), from which the Kappa subdivision had been removed by erosion before the prevalence of the Neocene waters which have so widely mantled the lower levels of this region with tufaceous cements and conglomerates. The mound is gently synclinal in structure and consists of a few feet of Iota conglomerates rising rather abruptly from gentle basal slopes. A Theta outcrop of only a few acres, lying chiefly in the interval between hill *E* and the Truncate mound, but extending also around the latter except on its east to southeast quarter, and embracing so much of the basal slopes of both elevations as has been denuded of its Neocene mantle, is by far the richest collecting ground in the Malone district. This interval is of anticlinal structure, the strata increasing their dip from either the neighboring base

of the Trio or that of the Truncate mound toward a common line, the axis of a closed fold, where they stand nearly vertical, and where is the shallow beginning of a small draw that deepens to the northward. This pinching and change of dip make difficult a close estimate of the thickness of upper Theta strata here exposed, but it does not seem probable that less than about 250 feet of these can have been involved in the exposed portion of either limb of the fold.

If we except obscure vestiges of fossils in the Kappa limestones and fragments of Paleozoic fossils (partly corals) in the pebbles of the Iota conglomerates, the fossils at this locality are confined to the Theta subdivision.

A very few forms, two or three of them identifiable as the commonest Malone species, were collected in the upper part of the Theta, chiefly in one bed of slight thickness, at a spot near the southwestern base of hill *C*, at the south border of the flat, saddle-like interval that separates the Trio from the west-northwestward continuation (*A*, *B*) of this hill range. In the immediate vicinity of this minor occurrence of fossils, and stratigraphically lower, is a small exposure of gypsum. This locality is only about half a mile west and a little north of the principal collecting ground above described.

The Iota subdivision of the Trio section consists distinctively of coarse conglomerates, in six or more beds 1 to 8 feet thick, separated by layers of relatively soft sandstone. Many of the pebbles and cobbles in these conglomerates are of iron-stained chert and siliceous limestone; some are evidently of Paleozoic derivation, and a few are of white quartz. In the southeastern slope of the east hill of the Trio the thickness of the Iota is about 50 feet. In the Truncate mound a considerable part of the original thickness has been removed. The dip of the Iota, like that of the other and generally much disturbed members of the Malone formation, is extremely variable in amount and direction. In the Trio and the Truncate mound it is usually from 15° to 25°, but exceeds the latter amount in places. On the southeastern slope of the Trio its direction is a few degrees west of north; in the east and west walls of the Truncate mound it is, respectively, west and east.

At the isolated hill (*G*) south of the railway, between one-half and three-fourths of a mile southeast of the main fossil-bearing locality, no fossils were found, nor any Malone rocks lower than Iota, though the typical succession of conglomerates of the latter subdivision is shown there, blanketed by Neocene at its base.

The Kappa, which forms the upper portion of the Trio—about 40 feet in hill *E*—is of hard, massively bedded, bluish-black, calcite-seamed limestone, charged with irregular segregations or impregnations of silica and iron. Much of it is cleft into large, rectangular

blocks by weathering along joint planes and bed planes in such a manner that it is not always very obvious which set of planes represents the dip except as this is indicated by underlying strata. It is impossible to say what thickness it may have had here formerly, as an unknown part of it has been removed by erosion.

At its base in the Trio the Kappa limestone presents a zone several feet thick, composed almost wholly of spherical, oval, or somewhat irregular concretions, from 1 to 3 or 4 inches or occasionally more in diameter. They consist of alternating lighter and darker layers, each a few millimeters thick, and sometimes weather uniformly with the matrix, being then seen in section, or are harder than the inclosing rock, when they are weathered out as pebbles, splitting sometimes into hemispheres which show the concentric layers. This is only an exaggerated sort of pisolitic structure. It is probable that this horizon, like others of the Malone formation, is variable, and that pisolitic structure is only locally developed in it. This rock is very probably similar to the pisolitic limestone conglomerate mentioned by Mr. Taff as constituting No. 9 of his Malone Mountain section.[a]

A reconnaissance was made of the western segment (*A*, *B*) of the Malone Hills, consisting chiefly of limestone and gypsum, with sandstone at its western end (as described by Mr. Robert W. Goodell in connection with his section of the Malone Hills)[b] and at least one remnant of conglomerate at its southern border; also of a ridge of quartzitic sandstone, apparently below the adjacent gypsum, and which forms an eastern foothill of Malone Mountain at the southern end of the mountain, and of portions of the eastern slope and summit of the mountain. But as these were for the most part only cursorily examined, and yielded no fossils except at one locality in the eastern slope of the mountain, no attempt will here be made to correlate positively their stratigraphic subdivisions with those observed at and southeast of the Trio.

Provisionally, however, it may be said that if the gypsum near the southwestern base of hill *C* represents the same horizon as the heavy bed that traverses the western segment of the Malone Hills, and if the latter is but a reappearance of the great gypsum bed the upper limit of whose outcrop disappears by descending northerly from the southern east front of Malone Mountain, then the following inferences would apparently be reached:

(1) That the same gypsum, though not exposed there, probably underlies the highly fossiliferous sandstones and limestones of the Theta at the east end of the Trio and at the Truncate mound.

(2) That the well-stratified limestones and the massive remnant of conglomerate lying above this gypsum and bordering it on the south

[a] Second Ann. Rept. Geol. Survey Texas, pp. 722, 723. [b] Jour. Geol., vol. 5, p. 817.

in the western segment of the Malone Hills would represent the Theta and the Iota in that quarter.

(3) That the conglomerates above the gypsum in the east face of Malone Mountain, at the southern end of the mountain and at the transverse anticline a mile farther north, would represent, in part at least, the Iota.

(4) That the Theta in the eastern slope of the mountain at its southern end would, if present, belong about at the summit of the gypsum, and that it either has been removed by erosion during the formation of the conglomerates or is possibly represented there by the upper part of the gypsum itself.

The fossils obtained by me from the eastern slope of the mountain were found in a ravine at the base of the mountain, in a horizon of impure limestone, at the passage from conglomerates like those of the Iota to limestones like those of the Kappa, forming part of an obliquely transverse anticline about a mile north of the southern end of the mountain; those collected at the latter locality by Doctor Stanton were obtained in part from limestones somewhat higher in the anticline.

DISTRIBUTION OF FOSSILS IN MALONE DISTRICT.

A large number of the fossils herein described will be found recorded as having been collected by Doctor Stanton at a number of points on or near Malone Mountain, especially on the western slope and foothills. The great majority of these had previously been found at the notable locality east of Malone, but several will be found listed from the mountain or its western foothills only. Among these are the Nautilus, a few other Mollusca, and the two echinoderms.

How prolific the Malone formation is in fossils at the several collecting stations, and how much the original Malone Hills locality excels the others, may be seen by the following lists:

OCCURRENCE OF SPECIES BY LOCALITIES.

LOCALITY No. 1.—*Theta subdivision of the Trio section in the Malone Hills, 1¼ miles east of Malone railway station.*

Astroccenia maloniana.
Serpula gordialis.
Serpula sp. (large).
Serpula sp. (small, with annular, filiform costellæ).
Berenicea maloniana.
Ostrea sp.
Gryphæa mexicana.
Exogyra subplicifera.
Plicatula sportella.
Lima (Radula) interlineata.
Lima (Ctenostreon) riograndensis.
Pecten insutus.
Gervillia corrugata.
Mytilus nuntius.
Modiola maloniana.
Pinna quadrifrons.
Arca? dumbli.

Arca taffii.
Cucullæa catorcensis.
Cucullæa texticostata.
Cucullæa transpecosensis.
Leda? navicula?.
Trigonia calderoni.
Trigonia conferticostata.
Trigonia goodellii.
Trigonia munita.
Trigonia proscabra.
Trigonia rudicostata.
Trigonia vyschetzkii.
Astarte? craticula.
Astarte? isodontoides.
Astarte malonensis.
Astarte microphyes.
Astarte posticalva.
Ptychomya stantoni.
Lucina? mexicana.
Lucina potosina.
Lucina potosina, var. metrica.
Unicardium semirotundum.
Unicardium transversum.
Cyprina coteroi.
Cyprina? streeruvitzii.
Tapes? cuneovatus.
Pholadomya marcoui.
Pholadomya paucicosta.
Pholadomya præposita.
Pholadomya tosta.
Pleuromya inconstans.
Pleuromya inconstans, var. curta.
Anatina obliquiplicata.
Anatina pliculifera.
Thracia? maloniana.
Martesia? maloniana.
Pleurotomaria circumtrunca.
Turbo? beneclathratus.
Delphinula stantoni.
Nerita nodilirata.
Nerita peroblata.
Vermetus cornejoi.
Natica bilabiata.
Natica inflecta.
Natica williamsi.
Chemnitzia goodellii.
Nerinea circumvoluta.
Nerinea goodellii.
Nerinella stantoni.
Cerithium arcuiferum.
Actæonina? maloniana.
Oppelia? fallax.
Olcostephanus malonianus.
Perisphinctes felixi.
Perisphinctes potosinus.
Perisphinctes schucherti?.
Aspidoceras alamitocensis.
Pycnodont fish tooth.
Cycloid fish scales.
Enaliosaur (fragments of bones, indicating animal of considerable size).

LOCALITY No. 2.—*South border of flat saddle, west of the Trio, about a mile east of the Malone railway station.*

Trigonia vyschetzkii.
Astarte malonensis.
Pleuromya inconstans?.

LOCALITY No. 3.—*Anticline in east slope of Malone Mountain, about a mile north of the southern end.*

Holectypus? sp.
Serpula gordialis.
Gryphæa mexicana.
Exogyra subplicifera (probable casts of).
Modiola maloniana.
Cucullæa catorcensis.
Leda? navicula.
Astarte malonensis.
Unicardium semirotundum.
Unicardium transversum.
Pleuromya inconstans.
Martesia maloniana.
Turritella burkarti.
Chemnitzia goodellii?.
Nerinella stantoni.
Selachian (fin spine of indeterminate genus).

LOCALITY No. 4.—*About a mile[a] east of the railway station of Finlay; apparently about the same horizon as the locality next below mentioned.*

Gryphæa mexicana.
Lima interlineata.
Pecten insutus.
Modiola geniculata.
Modiola maloniana.
Trigonia calderoni.
Trigonia proscabra?.[b]
Astarte malonensis.
Unicardium transversum.
Chemnitzia goodelli.
Nerinella stantoni.

LOCALITY No. 5.—*Foothills near the railroad, at northwestern end of Malone Mountain, a little over 2 miles east-southeast of Finlay station, not more than 200 feet above the gypsum bed; total exposure above gypsum bed here 540 feet; fossils all from middle hundred feet.*

Cucullæa castilloi.
Lucina potosina, var. metrica.
Lucina planiuscula.
Unicardium semirotundum.
Pholadomya paucicosta.
Nerita finlayensis.
Natica finlayensis.
Natica inflecta.
Nautilus naufragas.
Oppelia fallax?.
Perisphinctes schucherti.

LOCALITY No. 6.—*First high ridge west of Malone Mountain, about 2 miles west of Malone station, in No. 13 of Doctor Stanton's Malone Mountain section.*

Gryphæa mexicana.
Pecten insutus.
Trigonia munita.
Astarte malonensis.
Pleuromya inconstans.

LOCALITY No. 7.—*West of the north part of Malone Mountain, about 2 miles southwest of Malone station, in No. 13 of Doctor Stanton's Malone Mountain section.*

Gryphæa mexicana.
Pecten insutus.
Astarte malonensis.
Unicardium semirotundum.
Pleuromya inconstans.
Martesia maloniana.
Chemnitzia goodelli.
Nerinella stantoni.
Nautilus burkarti?.
Perisphinctes clarki.

LOCALITY No. 8.—*At same locality as the preceding, but from a horizon 220 feet higher, viz, No. 25 of Doctor Stanton's Malone Mountain section.*

Pygurus sp.
Gryphæa mexicana.
Pinna quadrifrons.
Pleuromya inconstans.

LOCALITY No. 9.—*West base of Malone Mountain, a short distance north of the southern end.*[c]

Gryphæa mexicana.
Exogyra potosina (broadly triangular phase).
Gervillia cinderella.
Gervillia? riograndensis.
Pinna quadrifrons.
Pholadomya cf. marcoui.
Pleuromya inconstans.
Pleuromya inconstans, var. curta.
Corbula? maloniana.

[a] Something more than this distance, a little south of east.

[b] A cast; it may possibly represent *T. præstriata.*

[c] On this collecting station, having previously referred in his field notes to a fresh-water limestone 75 to 100 feet below a quartzitic conglomerate at top of Malone Mountain a short distance north of its southern end, Doctor Stanton comments as follows: "In the field this was believed to be between the fresh-water horizon and the quartzitic conglomerate above mentioned. It is certainly several hundred feet above a horizon of the *Gryphæ mexicana* and Nerinea."

LOCALITY No. 10.—*Foothill west of Malone Mountain, about 2 miles north of its southern end; possibly same horizon as that of the preceding locality.*

Gryphæa mexicana.
Exogyra potosina (narrower phase).
Pecten insutus.
Pinna quadrifrons.
Astarte malonensis?.
Lucina potosina, var. metrica.
Pleuromya inconstans.
Perisphinctes aguilerai.

LOCALITY No. 11.—*Near southern end of Malone Mountain, west face, near top; stratigraphic relation obscure.*

Trigonia munita.
Nerinea goodelli.

LOCALITY No. 12.—*Conglomerate on west face and near top of Malone Mountain.*

Trigonia goodelli? (cast, larger than other specimens of this sp.)

LOCALITY No. 13.—*East slope of Malone Mountain near the southern end; 200 or 300? feet above the gypsum.*

Gryphæa mexicana.
Trigonia præstriata.
Oppelia fallax?.
Perisphinctes clarki.

AGE OF MALONE FAUNA.

The affinities of its fauna clearly refer the Malone formation to the Jurassic. The only evidence that at first thought might seem discordant is the occurrence of the genus Ptychomya, which, with one or two doubtful exceptions, has not been recorded hitherto from rocks older than the Cretaceous. But when it is remembered that, of the Cretaceous Ptychomyas, only one species occurs later than the Lower Cretaceous (Neocomian and Gault) and that this one, the *Pt. zitteli* of the western Alps, is from the Turonian, no species occurring in the higher (Senonian and Danian) stages of the Cretaceous, the occurrence of one or two species of Ptychomya in the upper part of the Jurassic is only that which it would be reasonable to anticipate. This genus occurs at Chillan, Chile, in rocks of debatable age, and it is thought by Doctor Steinmann to have been derived there possibly from the same bed that yielded his *Trigonia transitoria*, from which *T. vyschetzkii* is scarcely distinguishable. The *T. transitoria* occurs also at Caracoles, Bolivia, where, on the basis of the kind of rock attached to the specimen, Doctor Steinmann supposes it to hail from the Lower Cretaceous; but nearly all of the Mesozoic fossils that he lists from Caracoles he considers Jurassic.

The sections *Undulatæ* and *Costatæ*, to which several of the Malone Trigonias belong, are exclusively Jurassic,[a] and, if we except *Tri-*

[a] By Pictet and Campiche (Pal. Suisse; Terr. Cret. de St. Croix, p. 360. 1866) and Stoliczka (Pal. Indica; Cret. Fauna S. Ind., vol. 3, p. 311. 1871), the section *Undulatæ* is said to include some Cretaceous species, but by later authorities it is cited as exclusively Jurassic. Thus it occurs, according to Zittel's Handbuch (1881–1885) "Nur in Jura;" and according to Steinmann and Döderlein's Elemente (1890), "Oberer Lias—Oberer Malm."

gonia præstriata—represented by a single somewhat imperfect mold—none of the Malone Trigonias agree perfectly with generic sections hitherto known from Cretaceous rocks, exclusively.[a] The genus Trigonia is moreover generally considered one of the best of the Lamellibranch genera for purposes of stratigraphic diagnosis.

But it is to the ammonites that we must look for the strongest evidence of geologic age, these being generally regarded as the most critical of molluscan fossils as guides to stratigraphic correlation. And here, too, the evidence is clearly conclusive of Jurassic age. Though several of the genera are common to the Jurassic and Cretaceous systems, all of the known European analogues in species and subgeneric groups are Jurassic. The ammonitic genus of most frequent occurrence in the Malone is Perisphinctes, which is common to the two systems, but is almost exclusively Jurassic. Of the 366 known species of this genus[b] only four, described by Neumayr and Uhlig from the upper Neocomian of Saltzgitter,[c] are Cretaceous; and these belong to a group which the Perisphinctes species of the Malone formation do not at all approach. On the contrary, the species of Perisphinctes to which those of Malone show the closest affinities are those of the Tithonian.

It should be noted that while some of the molluscan fossils other than ammonites seem to indicate Kimmeridgian, or earlier than Tithonian age, this is more or less offset by the presence of the ordinarily Cretaceous genus Ptychomya.

LOCALITIES OF RELATED FAUNAS.

The only localities which present rocks known to correspond more or less closely with those of the Malone formation are in Mexico.

In the descriptive part of this paper it is noted that some of the fossils of the Malone formation are identical with some of those of the Alamitos beds, described by Castillo and Aguilera as occurring at the Sierra de Catorce in San Luis Potosi, and that others agree with species described by Doctor Felix from the Cerro de Titania in Oaxaca. The number of forms at present known to be common to the Malone and the Alamitos is so considerable that there can be little doubt that these two names represent approximately the same horizon. The ammonites of the Alamitos, like those of the Malone, are of Titonian affinities.

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[a] Doctor Stanton, however, places *Trigonia proscabra* in the Scabræ, and questions whether *T. calderoni* be not referable to that section also rather than to the Undulatæ.

[b] In the body of his recent Monograph of Perisphinctes, Siemiradzki treats 363 species of this genus. In its supplement, of a large number of additional alleged new species cited as described by De Rias and Tornquist in 1898, he identifies all but three with species previously known, so that the number of species recognized by Siemiradzki in the early part of 1899 was 366.

[c] Ueber Ammoniten aus den Hilsbildungen Norddeutschlands; Paleontographica, Bd. XXVII, 1881.

The number of fossils known from the Jurassic of the Cerro de Titanìa is small, but indicates, so far as it goes, a position high in the upper Jurassic series, as shown by Doctor Felix; and it is at least worthy of note that of the few lamellibranchs known from these rocks, *Exogyra subplicifera* and *Gryphæa mexicana* occur also at Malone, *Astarte microphyes* may be the same as *A. brexiacola*, and the large *Trigonia sologureni*, known only from the cast, may yet prove to be identical with the Malone species, *T. ryschetzkii*, when the details of its shell come to light.

Besides the Malone district, the Sierra de Catorce, and the Cerro de Titania, several other localities in Mexico have yielded fossils of the Malone formation. Thus a Perisphinctes, supposed to be related to the European *P. balderus*, is apparently common to the Theta and the Alamitos and is reported from Tutotepec also, in the State of Puebla, by Castillo and Aguilera; and by the same writers *Perisphinctes mazapilensis* and *Haploceras mazapilensis* are recorded from the Alamitos and from the Sierra de Zuloaga, in Zacatecas.

A number of Mexican Jurassic localities besides those here mentioned are given in Aguilera's "Sinopsis de Geología Mexicana;"[a] but these are little known, and at some of them the rocks belong, at least in part, to the lower Jurassic. It is, however, interesting to note that the Jurassic district of Malone is in the continuation of the belt along which are scattered all or nearly all of the Jurassic tracts shown on the geological map of Mexico of 1897 published with Nos. 4–6 of the Boletin del Instituto Geológico de Mexico.

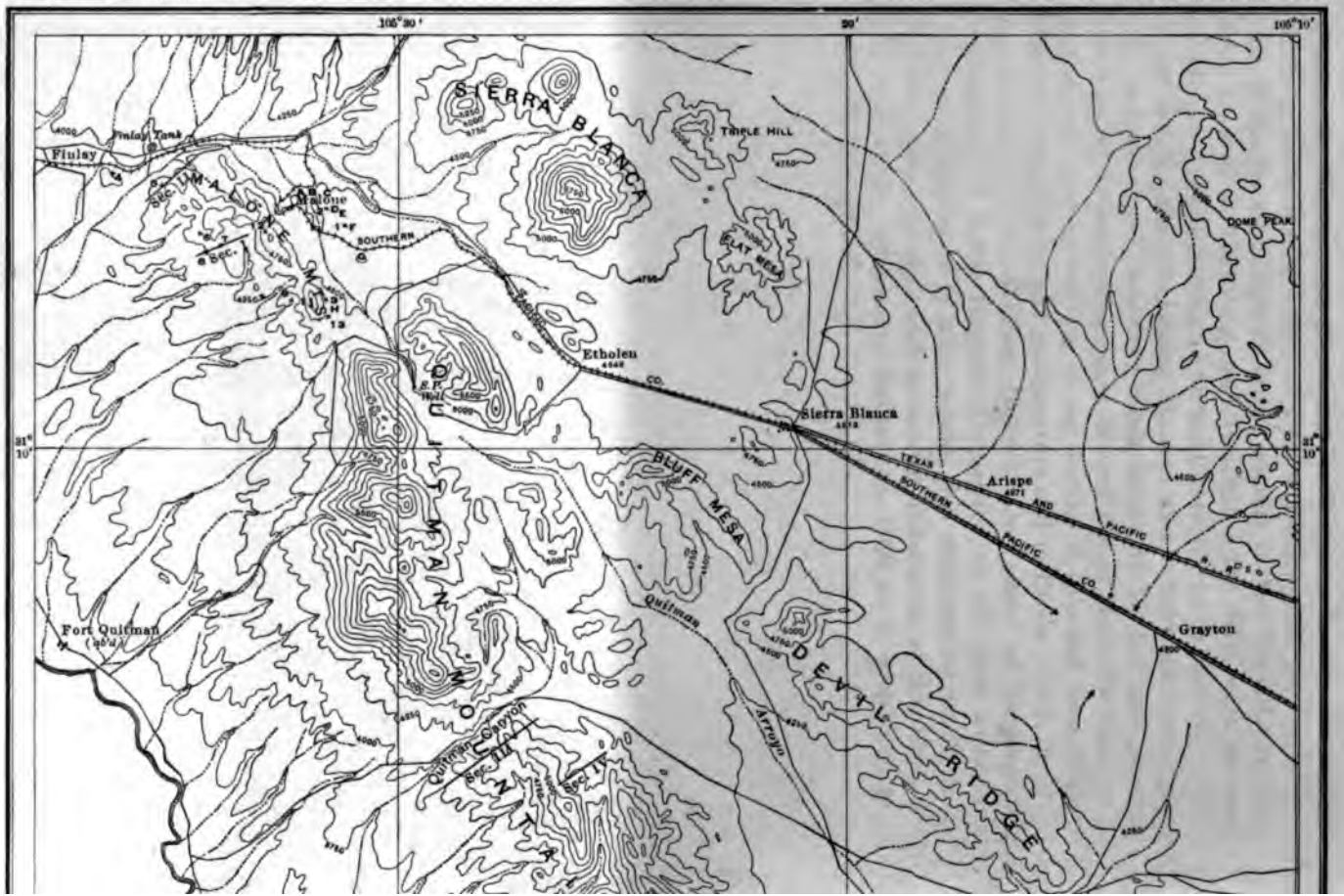
It is not improbable that rocks nearly related to the Malone occur in South America. As shown in the discussion of that species, *Trigonia ryschetzkii* is very close to the Andean form, *T. transitoria* Steinmann, a species whose precise geological position has hitherto been doubtful, but which the evidence from the Malone district tends to show probably belongs to the upper Jurassic.

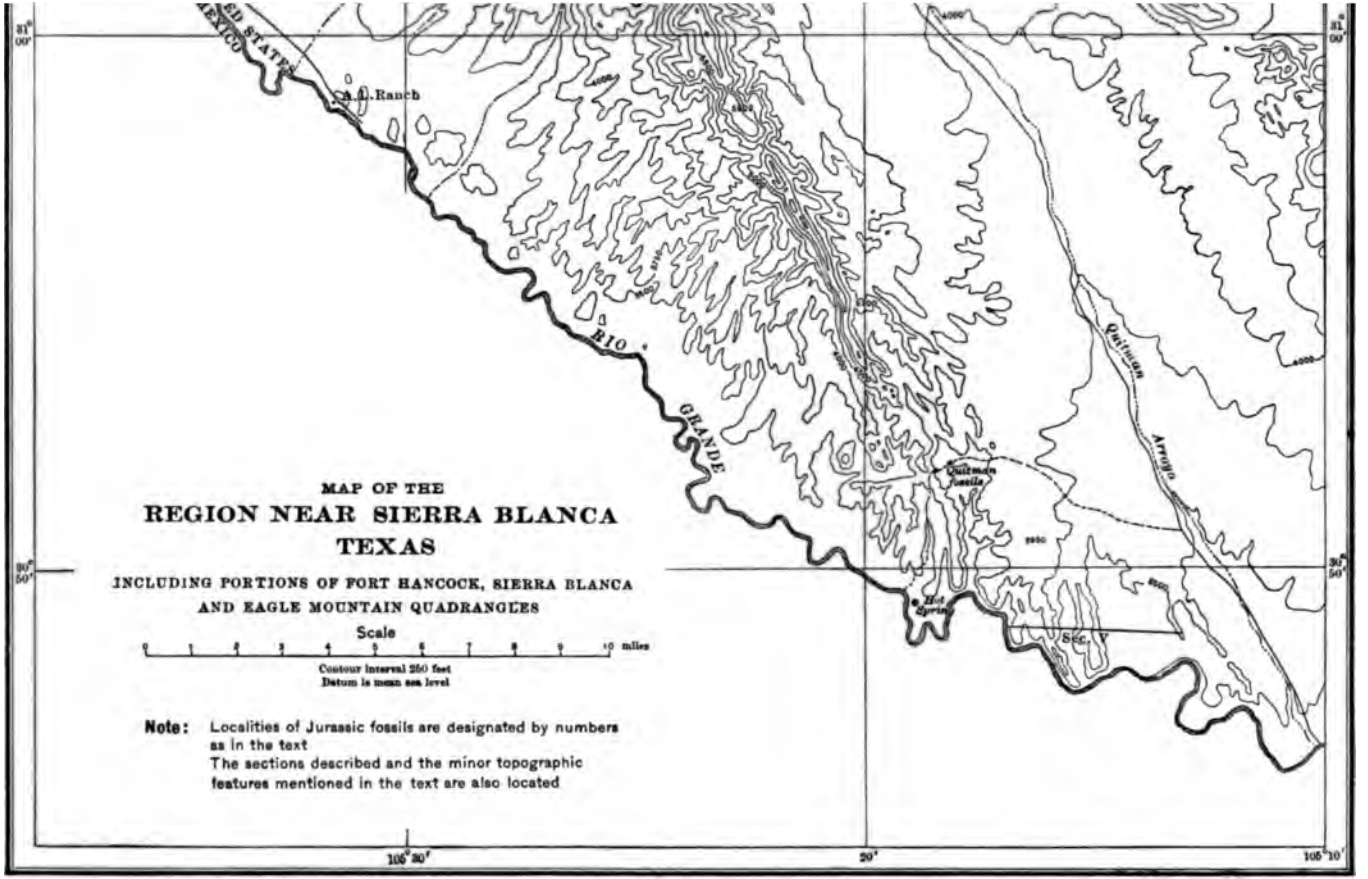
ACKNOWLEDGMENTS.

I wish to acknowledge my indebtedness to all of those mentioned elsewhere herein as having contributed directly or indirectly to the success of this study. The kind services of the Messrs. Goodell were of especial value, as furnishing the first fairly conclusive indication of the Jurassic age of the Malone formation. To the Hon. Charles D. Walcott, Director of the United States Geological Survey, and to Mr. Charles Schuchert, Curator of Invertebrate Paleontology in the United States National Museum, I am indebted for important aid. I am under obligations also to Mr. John N. Gilcrease, Mr.

[a] In Bosquejo, Geología de Mexico: Boletin del Instituto Geologico de Mexico, Nos. 4–6, pp. 187–250.

Charles M. Wilson, and Mr. John W. Williams for favors rendered while I made headquarters at Sierra Blanca, and particularly to Mr. Williams, who showed much interest in the Malone investigation, assisted in collecting, and facilitated the field work in every possible way, contributing in no small measure to its success. I deem it but simple justice to Doctor Stanton, and at the same time a pleasure, to state that I owe very much indeed to his full and generous cooperation in promoting every desired use of the collections under his charge, and in holding at my service a splendid knowledge of Mesozoic conchology and its literature and methods. And, finally, it is also due to Prof. William Bullock Clark, head of the geological department of Johns Hopkins University, to add that without his efficient planning of it as a whole, this contribution to American Jurassic paleontology could have been undertaken at this time, if at all, only under far greater limitations, both as to scope and as to facilities for research.


105°20'
20'
105°10'
SIERRA BLANCA
TRIPLE HILL
DOME PEAK
FLAT MESA
Finley
Finley Tank
Etholen
Sierra Blanca
BLUFF MESA
Arispe
Grayton
Fort Quitman
Quitman
DEVILS RIDGE
Arroyo
Quitman Canyon
31° 10'


MAP OF THE
REGION NEAR SIERRA BLANCA
TEXAS
INCLUDING PORTIONS OF FORT HANCOCK, SIERRA BLANCA
AND EAGLE MOUNTAIN QUADRANGLES
Scale
0 1 2 3 4 5 6 7 8 9 10 miles
Contour interval 250 feet
Datum is mean sea level
Note: Localities of Jurassic fossils are designated by numbers as in the text
The sections described and the minor topographic features mentioned in the text are also located
A.T. Ranch
RIO GRANDE
Quitman Arroyo
Quitman fossils
Hot Springs
Sec. V
31° 00'
30° 50'
105° 30'
20'
105° 10'

STRATIGRAPHIC NOTES ON MALONE MOUNTAIN AND THE SURROUNDING REGION NEAR SIERRA BLANCA, TEX.

By T. W. STANTON.

GENERAL REMARKS.

It has been deemed advisable to supplement Professor Cragin's paleontological paper by a brief account of the general geology of the region in which his Jurassic fauna occurs. The data here presented were obtained in 1897 and 1898 during two reconnaissance trips undertaken for the purpose of unraveling the obscure Cretaceous section of the Sierra Blanca region and, if possible, of determining the stratigraphic relations of the Malone Jurassic with the Cretaceous, as well as of making collections from all of the fossiliferous horizons of the region. The stratigraphy of the Cretaceous was determined fairly well, several fossiliferous horizons in the Jurassic of Malone Mountain were established, and interesting collections of fossils were obtained from both the Cretaceous and the Jurassic, but the rocks of the two systems were not found associated in the same continuous section, and their stratigraphic relations were not definitely determined.

In 1897 two weeks were spent at Sierra Blanca station examining the outcrops within a few miles of that station and one excursion was made 25 miles southward, to the Rio Grande. In 1898 a month was spent in the region working with a wagon and camp outfit, but even then many points could not be conveniently reached nor thoroughly studied because, on account of the scarcity of water and of roads, camping places were limited in number. The area examined comprises parts of the Fort Hancock, Sierra Blanca, and Eagle Mountain quadrangles, as mapped by the United States Geological Survey, extending from the Finlay Mountains on the north to the Rio Grande on the south and from the western foothills of Malone and Quitman mountains to Devils Ridge and Eagle Mountain on the east.

The region as a whole is characterized by rugged hills, ridges, and mountain masses rising abruptly from broad valley plains which are filled to an unknown depth with coarse Tertiary (?) deposits that obscure the structure of the older rocks beneath them. The general strike of the uplifted strata is northwest and almost all the smaller hills and ridges are monoclinal, with beds generally dipping southwest. In describing the Cretaceous deposits of this region in 1891, Mr. J. A. Taff[a] thought that the beds exposed north of the Sierra Blanca station are the oldest and that successively newer beds are found to the southwest except that there is some repetition by faulting. This opinion was based on the general posture and geographic relations of the beds and on the lithologic similarity of certain conglomerates and limestones in the Jurassic and the Cretaceous. The characteristics of the faunas involved were then practically unknown. It will be shown, however, that the real succession of strata is very different from that given in Mr. Taff's published section, the oldest Mesozoic rocks being found in Malone Mountain. Mr. Taff briefly discussed the folding and faulting that is common throughout the region and that is doubtless often present under the débris of the valleys as well as in the mountain masses. It would require much more time and study than has yet been given to this area to work out all its details of structure, which is further complicated by many intrusive masses of igneous rock in all the larger uplifts except Malone Mountain.

MALONE MOUNTAIN AND THE JURASSIC.

The strata bearing the Jurassic fauna described by Professor Cragin have been found only in Malone Mountain and the adjacent valleys. The Malone Mountain uplift extends from the Southern Pacific Railway near Finlay station about 5 miles in a southeasterly direction and ends abruptly a few hundred yards from the northwesterly extremity of the Quitman Mountains. Malone station, which is 13 miles by rail from Sierra Blanca station, is at its eastern base a little north of the middle. From this direction the mountain looks like a simple unbroken ridge, but on the southwest side it is deeply dissected by both transverse and longitudinal valleys.

The general structure seems to consist of a syncline along or east of the crest of the principal ridge, with an anticline in the valley and subordinate ridges of the west slope. There are also several minor folds, often beautifully shown, and doubtless some faulting. Toward the southern end of the mountain a small anticline is developed on the eastern slope. Mr. Taff has published a figure of the Malone Mountain section[b] showing these general structural features. He has

[a] Second Ann. Rept. Geol. Survey Texas, pp. 714–738. [b] Idem, Pl. XXVII.

also described [a] the succession of strata in the middle section of the mountain, which agree in the main with my observations, though both structure and exposures vary greatly in different parts of the uplift.

The most complete section that I observed, in which the thicknesses were estimated with some care, extends across the mountain from a point on the east side about one-half mile south of Malone station. The eastern face of the mountain shows an apparent thickness of about 1,200 feet of blue and gray limestones, with a few intercalated beds and bands of conglomerate and sandstone, the beds all dipping strongly westward with increasing dips until they become vertical on the crest. On the west slope there is a succession of limestones, conglomerates, and gypsum beds, nearly vertical and not well exposed, and farther down these are apparently repeated with a westerly dip, overlain by conglomerates, limestones, etc., fairly well exposed and not much disturbed in the lower ridges to the west. The gypsum beds and the limestones immediately associated with them appear to be the oldest rocks exposed. The following section begins with what was supposed to be the lowest gypsum bed, but on account of complex structure and obscure exposures the succession and thickness of the first five members are somewhat uncertain.

Section of Jurassic beds on west side of Malone Mountain, near Malone station (Section 1 of map).

	Feet.
1. Gypsum, not well exposed, about	100
2. Calcareous conglomerate, almost vertical	45
3. Mostly covered; limestone below, gypsum above (dip variable, westward), about	200
4. Altered and fissured limestone	125
5. Gypsum, not well exposed	100
6. Silicco-calcareous shale	40
7. Limestone	20
8. Covered (shale?)	100
9. Blue limestone, with traces of fossils	2
10. Covered	15
11. Arenaceous limestone	1
12. Covered	10
13. Blue limestone, with the Malone fauna	2
14. Covered	10
15. Limestone	1
16. Covered	8
17. Thin-bedded limestone and shales	20
18. Calcareous conglomerate	15
19. Limestone with Pleuromya and Gryphæa	15
20. Covered	10
21. Calcareous conglomerate	15

[a] Idem, pp. 722–723.

	Feet.
22. Limestone with fragmentary fossils (Ammonites, etc.)	10
23. Calcareous conglomerate	15
24. Covered	100
25. Limestone with Gryphæa, Pinna, Trigonia, etc	15
26. Covered in talus slope	150
27. Thin-bedded brown sandstone with bands of conglomerate and containing a small Ostrea, Nerinea, and a few other fossils, poorly preserved	25
28. Massive, gray, calcareous sandstone	10
29. Gray limestone forming a prominent ridge	±250
30. Brown conglomerate, composed mostly of quartzite and chert pebbles	40
31. Blue limestone	100

This is uncomformably overlain by the unconsolidated Tertiary or Pleistocene conglomerates of the plains on the west.

The main ridge of Malone Mountain on the line of this section seems to be made up of Nos. 29, 30, and 31, with perhaps some higher beds, all repeated by the synclinal fold.

Nos. 13 and 25 each yielded fossils, some of which are specifically identical with forms occurring at Professor Cragin's principal locality for the Malone Jurassic fauna, and the fossils mentioned in other bands (Nos. 9, 19, 22, and 27) evidently belong to the same fauna.

Some bands in the limestone No. 29 yielded a few fossils that seem to be fresh-water forms—small, simple gasteropods, resembling Viviparus. Similar forms were seen in No. 31 also.

Near the south end of Malone Mountain the same horizon in No. 29 yielded some small bivalves with the external features of Unio associated with the gasteropods. Conglomerate No. 30 of the section, however, contains marine fossils, including Ammonites, Exogyra, and several other genera. These were not found on the line of the section above described, but the conglomerate is a prominent, easily recognized horizon exposed at many points along the entire length of the mountain, and the fossils, usually in the form of imprints and fragments, were seen at several places both north and south of the section, especially toward the southern end of the mountain. In the western foothills of the mountain, 1 to 2 miles north of the southern end, there are exposures of a conglomerate believed to be the same as No. 30, and in the uppermost bands of the limestone immediately beneath it collections were obtained containing Exogyra, Pinna, Pecten, Pleuromya, Perisphinctes, etc., which Professor Cragin has assigned to the Malone fauna (see p. 19).

At the end of the northwest spur of Malone Mountain, at the point where it approaches the railroad, there are large exposures of gypsum that almost certainly belong to the gypsiferous horizons in the section just described, though they are separated from them by struc-

tural breaks.[a] In the following section the estimated thicknesses of the gypsum and the beds overlying are not closely accurate, because the exposures are very incomplete and the dips are variable and not easily determined.

Section near northwest end of Malone Mountain about 2 miles southeast of Finlay station (Section II of map).

	Feet.
1. Gypsum	100 or more.
2. Mostly covered, about	200
3. Limestones with conglomerate layers alternating with softer shaly bands. Several fossiliferous horizons with Malone fauna (see lists, p. 18)	75
4. Limestones passing into calcareous conglomerate	15
5. Limestone with a few Malone fossils	15
6. Calcareous conglomerate	6
7. Covered (shales and limestone)	20
8. Calcareous conglomerate	10
9. Blue limestone dipping 20° SW., with echinoids and large Nerinea seen in section on weathered surface	6
10. Blue limestone and shale passing under the plain	200

There can be little doubt that the fossiliferous beds in this section are on very nearly the same horizons as those in the section west of Malone station.

The most prolific locality for Malone Jurassic fossils, and the only one not directly connected with the mountain itself, is in the low hills in the valley about 1½ miles east of Malone station. The exposures are comparatively small and the dips variable, so that the stratigraphic details either as to thickness or succession can not be determined with certainty. Professor Cragin gives his observations on this locality fully in another place (pp. 13–17).

It is not possible to make a definite correlation of the fossiliferous beds here with any single horizon in the Malone Mountain sections, but it is most probable that they belong not more than 300 feet above the main gypsum beds.

At this point the Malone Jurassic beds are closer to fossiliferous Cretaceous beds of determined horizon than at any other place observed in the region. About 3 miles to the east, near the southwest base of Sierra Blanca, there are exposures of Washita beds with *Nodosaria texana* and *Gryphæa mucronata* (?), and the same horizon occurs a little farther away along the railroad between Etholen Hills and Quitman Mountains.

Mr. Taff correlated portions of the Malone Mountain section with exposures in the conical hills near Etholen about 5 miles west of

[a] Mr. Taff assigned these gypsum exposures, as well as those at the southeast end of the mountain, to a higher horizon (see pp. 725 and 736 of his report), but they all have the same relations to the fossiliferous horizon bearing the Malone fauna.

Sierra Blanca station, and in Bluff and Yucca mesas near the same station, but I was unable to confirm these correlations. The strata in the "Etholen Knobs" may possibly belong here, but the other localities almost certainly show only Cretaceous beds.

THE CRETACEOUS.

Cretaceous rocks have a great development in this region and represent the three main divisions of the Comanche series—the Trinity, Fredericksburg, and Washita—as well as a part of the Upper Cretaceous. Lithologically the section differs greatly from that of Central Texas, where the Comanche series has been most studied, and there are also considerable differences in the vertical range of some of the common species, so that it is impracticable to recognize many of the minor formations and horizons that have been studied. The general faunal succession is the same in both regions, and it is usually not difficult to classify the beds by means of the fossils as Trinity, Fredericksburg, or Washita, though it was difficult and sometimes impossible to assign each exposure to its exact position in the general section, because many of them are relatively small and isolated, and the structure is complicated by folds, faults, and igneous intrusions. The most complete sections are to be found in the Quitman Mountains, especially toward the southern end and in the lower hills farther south on the Rio Grande, in the southern extension of the same line of uplift.

Quitman Mountains.—This range begins at a point on the railroad 8 miles west of Sierra Blanca station and extends in a southeasterly direction about 25 miles, the uplifted beds continuing as low ridges in the same direction and crossing the Rio Grande 6 or 7 miles beyond the end of the main range. At its northern end it is composed mainly of igneous rocks—granites and porphyries—with Cretaceous beds in the adjacent foothills on the north and east, but south of Quitman Canyon, a drainage channel that cuts straight across the range about 10 miles south of its northern end, the mountain mass is composed of Cretaceous sediments, with only occasional igneous intrusions. The axis of the range is for a number of miles almost parallel with the Rio Grande, which flows about 6 miles to the southwest, while on the other side is the flat valley of Quitman Arroyo, 4 to 10 miles wide, separating the Quitman Mountains from Devils Ridge and Eagle Mountains. Sections taken at different points across this range vary greatly in extent. The one published by Taff in the report cited was taken near Quitman Canyon (Section III of map), and shows the strata with variable steep dips mostly to the west, but sometimes reversed. Near the eastern end of the section is a heavy bed of limestone, forming part of Taff's "Bluff bed," filled with *Orbitolina texana* and a

few other forms, followed by a band of hard limestone containing numerous specimens of Requienia. Then comes the "Quitman bed," composed of sandstones, clays, and thin beds of limestone, with a thickness of 330 feet, succeeded on the west by a great series of sandstones and siliceous limestones, the "Mountain bed," with an apparent thickness of about 4,000 feet. The western end of the section was thought to be the top, and the entire section was referred to the Washita division of the Comanche series. My studies of more complete sections farther south in the same range, especially the one near the Rio Grande, led to the conclusion that the beds at Quitman Canyon and for a long distance southward are mostly overturned, and that the oldest rocks are on the west side of the mountains.

The Mountain bed, consisting mostly of coarse, varicolored sandstones, forms the western portion of the mountain all the way to the Rio Grande at Hot Springs, where it dips to the east instead of to the west. Its apparent great thickness may be due in part to folding and faulting. It has yielded only imperfectly preserved Ostrea and a few other forms that are insufficient for its correlation with established formations.

The Quitman bed has a similar distribution along the higher (western) slope of Quitman Mountain. Its fauna shows a different facies from any assemblage in the Central Texan section, including *Exogyra quitmanensis*, *Trigonia taffii*, *Trigonia stolleyi* (?), *Remondia*, and a considerable number of forms that will be described in a monograph of the Comanche fauna. Although some of the species show relationship with later faunas the stratigraphic and paleontologic evidence as a whole is thought to justify its assignment to the Trinity division. The best localities found for collecting this fauna are on Quitman Mountain about 1 mile south of Quitman Canyon, and on the trail from Quitman Arroyo to Hot Springs, about 3¼ miles from the springs.

The Orbitolina limestone for many miles forms the crest of the Quitman Mountains, with a bold escarpment on the east and a steep slope corresponding with the dip on the west. Its characteristic foraminifera, *Orbitolina texana* (Roemer), occurs only in the Glen Rose beds of the Trinity division in Central Texas. Another species of the same horizon that occurs with it in the Quitman Mountains is the large *Natica praegrandis* Roemer, which is usually treated as a synonym of *N. pedernalis*. The Orbitolina limestone has here a thickness of at least 250 feet, and farther south on the Rio Grande it appears to be still thicker, and the Orbitolina again appears in a thinner limestone about 300 feet higher.

On the eastern slope of the mountain 1 to 2 miles south of Quitman Canyon there are exposures of several hundred feet of limestones, clays, and sandstones dipping toward the mountain and apparently

underlying the Orbitolina limestone (Section IV of map). The succession from the Orbitolina limestone eastward down the mountain is as follows:

	Feet.
1. Alternating thin beds of sandstone and clay, with occasional bands of limestone; *Exogyra texana* near the middle	200
2. Alternations of limestone and covered spaces	200
3. Sandstone	8
4. Covered	15
5. Sandstone with *Actæonella dolium*	15
6. Argillaceous limestones, clays, and some arenaceous bands, with occasional layers containing *Exogyra texana*	300
7. Limestone in several massive beds interstratified with more or less argillaceous nodular beds; some of the harder bands full of *Caprina occidentalis* Conrad	75

Farther east some of these beds are repeated, dipping eastward. It is evident that these beds are in part the equivalent of those described by Taff as occurring in Flat Mesa, 4 miles north of Sierra Blanca, and that they should be included in the Fredericksburg division.

About 10 miles south of Quitman Canyon and less than 2 miles south of the northern boundary of the Eagle Mountain quadrangle the east face of the mountain shows a similar section, and at its base there are small exposures of Washita beds with *Schlænbachia vespertina* and a few other forms, dipping toward the mountain and thus giving additional evidence of overturning and faulting.

The Rio Grande section.—Still farther south, near the Rio Grande, the upper part of the section is much more complete and more simple, furnishing the key to the sections already discussed, which are parallel with it across the same line of uplift. The eastern end of the section is about 1 mile north of the Rio Grande in the first hills west of the board valley of Quitman Arroyo. Here the beds are sharply folded and a prominent ridge shows an anticline consisting of argillaceous limestone belonging to the Washita division.

The western limb of the anticline dips 70° to 80° west, and the exposure is as follows:

Section in hills just west of Quitman Arroyo, about 1 mile north of the Rio Grande (Section V of map).

	Feet.
1. Argillaceous limestone, weathering in nodular form, with bands of harder limestone	200
2. More massive limestone, much seamed and fissured	30
3. Dark, fissile shale, with occasional bands of impure brown limestone, underlying a valley about 1 mile wide. Dips at first steep to the west, becoming variable and much less toward the middle of the valley and again steep to the west on the west side of the valley. *Inoceramus labiatus* and a few other Upper Cretaceous fossils were found west of the middle of the valley; thickness apparently *several thousand feet.*	

	Feet.
4. Massive limestone, probably same as No. 2	30
5. Argillaceous limestone with some bands of clay and sandstone; fossils: *Nodosaria texana*, *Enallaster texanus*, *Neithea texana*, *Exogyra arietina*, *E. drakei* var., *Plicatula incongrua*, and other Washita forms	300
6. Heavy-bedded limestone (40 feet) forming a cliff, followed by argillaceous nodular limestone (30 feet), which yielded *Enallaster texanus*, *Gryphæa corrugata*, *Lima waconensis*, *Neithea texana*, and *Schlœnbachia vespertina*	70
7. Similar limestones with dip not less than 45° westward	300
8. More argillaceous light-gray limestone, interstratified with dark clay shales; one of the limestone bands yielded *Epiaster whitei*, *Terebratula* (*Kingena*) *waconensis*, *Gryphæa washitaensis* (?), *Plicatula incongrua*, and *Schlœnbachia vespertina*, and another band farther west yielded *Epiaster whitei*, *Schlœnbachia acutocarinata*, *S. serratescens*, and *Hamites fremonti*	300
9. Dark clays with brownish calcareous bands; *Exogyra texana* abundant	50
10. Covered	100
11. Limestone, very heavy-bedded above, with increasing bands of argillaceous limestone below; Requienia and a small conical Foraminifera abundant; *Exogyra texana* also occurs	300
12. Shales, limestones, and bands of brown sandstone, not well exposed	250
13. Argillaceous limestone, with some harder bands containing "Caprina" and Requenia	75
14. Generally more massive limestone with some bands of brown sandstone. Also contains "Caprina," Ostrea, etc	350
15. Quartzitic sandstone with thinner bands of clay shale and impure limestone, dipping steeply westward	400
16. Hard, blue limestone, full of *Orbitolina texana*	60
17. Sandstone and impure limestone with some clay	40
18. Sandstones and clays	250
19. Thin-bedded passing into massive limestone, full of *Orbitolina texana*; at least	300

The steep western surface of No. 19 forms the eastern wall of the canyon of the Rio Grande at this point.

So far there has been no apparent serious break in the section, but the beds now become complexly faulted and folded. A short distance north No. 19 is cut off by a fault, and on the west, across the river, the same bed seems to be repeated in several postures.

It is evident that the eastern portion of the section crosses a syncline, so that in passing from No. 1 to No. 5 the same beds are all crossed twice. In the rest of the section, while there may be some repetition of beds due to small faults, there are no anticlines nor synclines, and the fossils show that in general the beds are successively older toward the west. No. 3 is Upper Cretaceous, of the age of the Fort Benton; Nos. 4 to 8 are Washita; Nos. 9 to 14, and probably 15, are Fredericksburg; and Nos. 16 to 19 belong to the Trinity. As the dips are all steep to the west it follows that all the

beds from No. 4 to No. 19, inclusive, are overturned. It will be seen also that the succession of rocks and fossils is similar to that found on the east slope of the mountains near Quitman Canyon, and that there is no place for the great sandstone series of the "Mountain bed" within the Washita division. It must be older than the Orbitolina limestone.

Eagle Mountains.—These mountains, which lie 10 miles east of the southern end of Quitman Mountain, are composed mostly of igneous rocks, but sediments are exposed on their flanks. My examinations were along only the western base, where there are some exposures of Fredericksburg limestone and shales and apparently some Trinity limestones. Mr. Taff reports Upper Cretaceous and the Orbitolina limestone on the other side of the mountains, and fossils in the collection of Prof. W. F. Cummins, at Dallas, indicate the presence of upper Washita beds "1 mile north of gap in Eagle Mountains."

Sierra Blanca.—This group of conical peaks, about 6 miles northwest of the railroad station of the same name, is also composed of igneous rocks with Cretaceous sediments around the base. On the southwest side of the main peak there are fossiliferous exposures of Fredericksburg age noteworthy for containing *Exogyra texana* and *Nodosaria texana* in the same bed. The same association is found in the Finlay Mountains also. Beds of about the same age with *E. texana* and *Actæonella dolium* occur in Flat Mesa, about 4 miles east.

In the saddle between the main peak and the north peak of Sierra Blanca there are considerable exposures of very fossiliferous Washita beds with many characteristic species.

Finlay Mountains.—These hills begin about 4 miles north of the north end of Malone Mountain and 6 miles northwest of the main peak of Sierra Blanca and extend several miles to the north and northwest. They were rather hastily examined in the hope of finding an extension of the Malone beds, but the only fossiliferous beds seen belong to the Fredericksburg division of the Cretaceous, including the horizon of *Actæonella dolium*. There are many intrusive masses of igneous rocks and at one locality a considerable development of a coarse calcareous conglomerate whose relations were not definitely determined, though it seemed to belong to the Cretaceous.

Other localities.—Other exposures in the neighborhood of Sierra Blanca station were examined, especially Bluff Mesa and Devils Ridge, without very definite paleontological results. The top of Bluff Mesa, 3 miles southwest of Sierra Blanca, is composed of Orbitolina limestone, and it is probable that the underlying beds belong within the Trinity division.

The Orbitolina limestone, the Quitman bed, and a considerable thickness of Fredericksburg beds are well exposed in the neighbor-

hood of the abandoned "A L Ranch" on the Rio Grande west of Quitman Mountains, in the small triangular area bounded by the river and the Eagle Mountain and Fort Hancock quadrangles. The Fredericksburg beds are especially well exposed about 2 miles down the river from the ranch, in the small canyon locally known as the "Cajoncito." The next prominent ridge, 3 or 4 miles to the east, shows Washita shales and limestones, with intervening dark shales that may belong to the Upper Cretaceous.

These details of the stratigraphy and distribution of the Cretaceous in this region are given for the purpose of emphasizing the peculiarities and the isolation of the Malone beds.

DESCRIPTIONS OF THE SPECIES.

CŒLENTERATA.

ANTHOZOA.

Several coralla of the massive shape and a segment of a digitiform branch, which in my preliminary manuscript on the Malone fauna I had described as two species of Astrocœnia, were eventually submitted to Mr. T. Wayland Vaughan, who is engaged in a special study of the Neozoic corals, for more detailed study than I could give them. Of these, Mr. Vaughan has very kindly furnished the following description:

Genus ASTROCŒNIA M. Edwards and Haime.

ASTROCŒNIA MALONIANA sp. n.

Pl. II, figs. 1–3.

"Professor Cragin has submitted to me for study and description 9 specimens of an Astrocœnia collected by him 1½ miles east of Malone, Tex. The original substance of the skeleton has been transformed in the process of fossilization into a bluish limestone; the skeletal elements are now represented by crystalline calcite and the interspaces are filled by the same mineral. The result of these chemical changes is to make a study of the thin sections of the specimens very unsatisfactory. No minute structural features could be deciphered, and very often even the grosser ones of the individual corallites are obliterated or can be discovered only with difficulty.

"Apparently only one species is represented in the collection, but there is a central or type form around which the other specimens can be grouped. The type form will be described first.

"The corallum is a gibbous mass, with a flat base having a rather large surface; the upper surface is rather uniformly rounded or thrown into numerous mammillæ. The intergradation between these two types of upper surface can be seen in the specimens before me. When the mammillate character has reached its maximum development the external appearance of the corallum is identical with that of the common recent West Indian *Porites astreoides* Lamarck. The dimensions of two large specimens, both of which possess the mammillate upper surface, are:

	mm.	mm.
Greatest breadth	113	96
Least breadth	95	82
Height	52	56

"The above represents the type form of the corrallum. There is one specimen, with a mammillate surface, which shows no place for attachment, and other specimens show a tendency to form low columns.

"The corallites are polygonal, usually hexagonal, are crowded together, and are joined by their directly fused walls. The wall between adjoining corallites is usually thin, but in some instances it may be rather thick, in extreme cases almost 1 mm. When the wall is thin, its upper edge is acute; when it is thick, it is flattened between adjoining calices. The depth of the calicular cavity is so variable that it possesses no value in the specific diagnosis; it is sometimes deep and sometimes very shallow in the same colony. The diameter of the calices vary in the same colony from 1.5 to 2.5 mm. The minimum diameter for a calice is 1 mm. and the maximum is about 3 mm., or a very little less. The number of septa is 16 or 20. There are either 8 or 10 principal septa, with smaller ones between. At their margins the septa are usually rather thin, but deeper down in the corallite are secondarily thickened. The septa are thicker peripherally at the wall and are also thickened around the columella. The septa of adjoining corallites meet end to end or alternate with each other. In transverse sections of corallites dissepiments are very rarely present. No further information can be given concerning the endotheca. The columella is small, low, weak, and styliform. Below the bottom of the calice it is strengthened by having the thickened inner terminations of the principal septa fuse around it. Gemmation takes place in the angle between adjoining corallites.

"There is another specimen not included in the above. It is an Astrocœnia, apparently growing in digitate branches. There is not enough material to warrant naming and describing it."

ECHINODERMATA.

ECHINOIDEA.

HOLECTYPOIDA.

Genus HOLECTYPUS Desor.

Holectypus? sp.

An echinoid fragment indicating a test shaped as in this genus, but with the details too poorly preserved to allow a satisfactory description or an absolute generic identification, was obtained by Doctor Stanton from an anticline on the east slope of Malone Mountain, about 1 mile north of the southern end.

SPATANGOIDA.

Genus PYGURUS Agassiz.

PYGURUS sp.

Among the specimens submitted by Doctor Stanton is a fragment of the test of a sea-urchin of the genus Pygurus. It includes the main part of the aboral half of an ambulacrum. The genus is clearly determined by the form of the ambulacrum and the form and arrangement of the pores, as well as by the character of the tubercles and by the discoidal form of the test, the latter form being indicated by the flatness of the part preserved. The ambulacrum has the biconcave outline that characterizes the upper part of that of Pygurus. The pores of the outer row are very long and slit-like, widened slightly toward the outer end, and subhorizontal to more or less oblique; those of the inner row more ringent, compressed dot-like or hyphen-like, and oblique, their width being considerably less and their length considerably more than that of any of the circumtubercular courts on the neighboring part of the ambulacrum. The ambulacral plates are exceedingly narrow; the imperforate part of each, in the widest part of the ambulacrum, being about ten times as long (transverse) as wide (parallel to the course of the ambulacrum) and ornamented with 1 to 3 small perforated tubercles, each of which is set in a round, depressed court. The distribution of these tubercles is irregular, but they are so few and so feebly developed on the inner ends of the plates as to give the ambulacrum the aspect of having a median plain zone, to which the seams between the plates give a transversely striated appearance.

Measurements.—Maximum width of ambulacrum 16, of which the two pore belts each occupy 3.5 and the imperforate tract 9 mm.; length and width of imperforate part of an ambulacral plate in broadest part of ambulacrum, respectively, 4.5 and 0.43 mm.; length of outer slit-like pores in broadest part of ambulacrum 2 mm., which is about one-fourth of the width of a semiambulacrum.

Occurrence.—West side of Malone Mountain, about 2 miles southwest of Malone station, in No. 25 of Doctor Stanton's Malone Mountain section; with *Gryphæa mexicana*, *Pleuromya inconstans*, *Pinna quadrifrons*, etc.

VERMES.

ANNELIDA.

TUBICOLA.

Genus SERPULA Linnæus.

SERPULA GORDIALIS Schlotheim.

Pl. II, figs. 5–6.

A round-tubed, nearly smooth, irregularly constricted, at first spirally coiled, then contorted Serpula, probably the same as that noted by Doctor Felix[a] from the upper Jurassic rocks of the Cerro de Titania in the State of Oaxaca, Mexico, and referred by him to Schlotheim's *S. gordialis*, is the commonest tubicolan of the Malone fauna, having been found at the anticline in the eastern base of Malone Mountain (in both Doctor Stanton's collections and mine), and at the locality 1½ miles east of Malone station. The largest tubes observed measure about 2.7 mm. in diameter, 1 to 2 mm. being a more common size.

SERPULA sp.

Pl. II, fig. 4.

Not rare at the locality last mentioned is a large Serpula, apparently differing from *S. gordialis* chiefly in size, but perhaps also having a less constantly or less intricately contorted habit. As there found, it attains a diameter of at least 8 mm.

SERPULA sp.

A single specimen of a third and well-marked species of Serpula was obtained from the same locality, but was lost in the laboratory when it had received only preliminary study. The following are its characters so far as they were noted:

Tube considerably smaller than an average one of *Serpula gordialis*, straight, round, and at least in part terete, its exterior ornamented with close, uniform or nearly uniform, prominent, filiform, encircling costellæ, so that its appearance recalls one of the smaller of the wound wires in the lower register of a piano; an ornamentation which contrasts strikingly with the plain to feebly and irregularly constricted exterior of the two other known Serpulæ of this district.

[a] Beiträge Geol. u. Pal. Mex., pt. 3, p. 175. Palaeontographica, vol. 37, 1891.

MOLLUSCOIDEA.

BRYOZOA.

DIASTOPORIDÆ.

Genus BERENICEA Lamouroux.

BERENICEA MALONIANA sp. n.

Pl. II, fig. 7.

Colonies incrusting, sometimes confluently associated, unsymmetrically flabelliform, apparently without a tattered or incised border; cells numerous, several hundred in a colony, tubular, arising as if separately in quincunx-radial order from the smooth or finely porous membrane-like stock which separates them by intervals for the most part about equal to themselves, the lower part of each cell being embedded and subhorizontal, the outer part rising obliquely and becoming gradually free or nearly so, being wholly free at the very extremity only; free surface of cells plain or at most only finely striate; oral extremity contracted, the aperture small and round.

Measurements.—Breadth of colony, 12 mm.; of cell, 0.2 mm.; of oral aperture, about 0.1 mm.; greatest exposed length of cells between twice and thrice their breadth.

Occurrence.—The type specimen covers between a fourth and a third of one of the larger whorls of a *Nerinea goodellii* and parts of the two whorls preceding and following, and is met by another similarly radiating colony of which only a border portion is preserved, the line of contact of the two colonies being heaved up into a ridge. It is from the locality 1½ miles east of Malone station.

In the partially embedded cells and in the resulting apparent separation of the tubes from each other this species resembles *Berenicea microstoma* Mich., as illustrated in fig. 6b of Pl. I of Reuss's "Bryozoen, Anthozoen und Spongiarien des Braunen Jura von Balin bei Krakau,"[a] but it lacks the undulatory transverse furrows of that species and has the tubes less strongly inflated and proportioned much as in the *B. tenera* Reuss. The last-named species is, however, very different in having the tubular cells visibly in contact instead of separated by a conspicuous basal stratum that conceals their deeper and contiguous parts.

[a] Denkschr. k. Akad. Wiss., Math.-Nat. Classe, vol. 27. Wien, 1867.

MOLLUSCA.

PELECYPODA.

OSTREIDÆ.

Genus OSTREA Linnæus.

OSTREA sp.

Three imperfect valves of an ovate, thin-shelled ostreid, about 1½ inches in greatest dimension, lie partly embedded on a piece of blue limestone obtained from the Theta, 1½ miles east of Malone station, and may represent Ostrea as distinguished from Exogyra and Gryphæa. They are, however, incomplete in the region of the beaks and their precise relationship therefore remains somewhat uncertain. The inflation is moderate and due almost wholly to the strongly incurved border, the remainder of the valve being rather flat.

Since in general aspect they recall species of Ostrea in the stricter, and certainly at least represent it in the broader generic sense, while they do not seem referable to any of the hitherto described Ostreidæ of the Malone Jurassic, they are here provisionally listed as above.

GRYPHÆA MEXICANA Felix.

Pl. III, figs. 1–6.

Gryphæa mexicana Felix, 1891, Beitr. Geol. u. Pal. Mex., pt. 3, p. 178, pl. 27, figs. 30, 30a.

Shell rather small, more or less inequilateral and cuneate; adductor scar elongate, lightly impressed; margins of the valves not crenulated internally, the right valve very much smaller than the left, rounded-triangular, usually flat or exteriorly in part concave, thickened in the dorsal part; left valve triangular to crescentic-triangular, deeply excavated, strongly arched on the dorsal region, the posterior part more prominently so than the anterior, its beak high-arched, strongly incurved and rather bluntly (seldom freely) hooked, usually swinging a little backward, its posterior side strongly flattened or concave, the passage thence to the outer side more or less angulated or sometimes elevated as an obtuse fold, a similar but smaller flattening or concavity being often present on the shorter, anterior side, exterior side usually convex—sometimes flattish or concave—antero-posteriorly and either without bordering sulci or provided with an anterior or posterior sulcus or with both; the growth-lines sometimes acute and imbricated, especially on the anterior and posterior slopes, but on the exterior slope often more commonly thickened at irregular intervals into obtuse wave-like elevations and often here also swung upwards into a broad sinus. In specimens of smaller and

medium sizes at least, the left valve is often ornamented with fine, radiating raised lines, including more conspicuous ones, which are rather remote, and numerous closely arranged, almost microscopically fine ones, there being usually 2 to 7 of the latter in each of the intervals between the former. This ornamentation is usually well expressed in very young examples, and these present considerable resemblance in form as well as sculpture to certain species of Plicatula, but in the arched valve, held beak upward and seen in exterior view, the longer side will appear on the right in the young Gryphæa and on the left in Plicatula, since the arched valve is the left in Gryphæa and the right in Plicatula and the posterior side of the shell is longer than the anterior in both genera. A very similar ornamentation is seen on the arched valve of Meek and Hayden's Black Hills Jurassic form, *Gryphæa calceola* var. *nebrascensis*. In exceptional specimens, *G. mexicana* approaches the latter species in form also, tending to a uniform antero-posterior convexity, even the posterior flattening being slight. Much more common than this, however, is the occurrence of specimens with anterior and posterior sides both strongly flattened or concave.

Measurements.—Specimens of an ordinary size give height, 43 mm.; length, 32 mm.; breadth, 17 mm.; but considerably larger specimens are often found.

Occurrence.—Common at several levels below the Iota conglomerates, a mile and a half east of Malone station, where scores were collected, and less so a few feet above similar conglomerates in an anticline in the east flank of Malone Mountain; in the latter locality associated with *Pleuromya inconstans*, *Modiola maloniana*, *Astarte malonensis*, *Exogyra subplicifera?* and *Serpula gordialis*. The species was also collected by Doctor Stanton, both at these and at the following localities: About a mile east of Finlay station; west side of Malone Mountain, west and also south of west from Malone station (at the last-named locality in Nos. 13 and 25 of his Malone Mountain section); from foothills west of Malone Mountain, about 2 miles north of its southern end; at the west base of the mountain, near its southern end; and from the east slope of the mountain, near its southern end, 200 or 300 (?) feet above the gypsum.

One of the most striking features of *G. mexicana* is the posterior flattening of the left valve, a feature of which is much more strongly expressed in this shell than in any other species of Gryphæa with which I am acquainted.

The prevailing size of the shell is not the same at all localities, some specimens of the largest average size coming from the west side of Malone Mountain; but at no locality in the Malone district does the shell average so small as the Oaxaca examples figured by Doctor *Felix*.

Genus EXOGYRA Say.

EXOGYRA SUBPLICIFERA Felix.

Pl. IV, figs. 1–4.

Exogyra subplicifera Felix, 1891, Beitr. Geol. u. Pal. Mex., Pt. III, p. 177, pl. 27, figs. 6, 7.

From locality 1½ miles east of Malone station, and associated with most of the commoner fossils described in this paper, were collected 19 specimens, besides 8 obtained by Doctor Stanton. Two somewhat doubtful casts were also found, with *Gryphæa mexicana*, *Astarte malonensis*, etc., just above the beds of conglomerate, at the eastern base of Malone Mountain, in the anticline about 1 mile north of the southern end of the mountain.

The shells occur both free, or nearly so, and attached by nearly the whole of the left valve. The largest example from the Malone Hills has a length of 35 mm., but some of the smaller ones agree nearly in size with the Mexican specimens described and figured by Doctor Felix from the Cerro de Titania. The right valve has the beak strongly recurved laterally, and sometimes has the anterior dorsal border drawn across the umbonal cavity so as to form more or less of a cul de sac, and in the more nearly free examples is rather thin, deeply excavated, and ornamented with numerous imbrications which present distally an obtuse angle on the summit of convexity, and in some of the young examples may have 1 to 4 faintly expressed radial folds on the basal part. In young specimens the right valve is more or less triangular, broad across the distal part, and a little produced at the base; in the adult it usually becomes auriform.

The following is a translation of the original description by Doctor Felix, relating to the right valve, which is exceedingly characteristic and on which alone the species was established:

> It is of auriform—sometimes rather elongate, sometimes more broadened—contour, like the Cretaceous *Exogyra auricularis* Brongn. sp., which has been regarded by Coquand as a variety of his *E. plicifera*. On its inner surface it bears a variable number, mostly 5 to 8, of transverse folds, which are in strong relief, but do not extend across the entire shell breadth, by which sculpture it is especially distinguished from related forms. It may be taken for granted that if adult examples show this sculpture on their inner side, free or only umbonally adnate individuals will show it on their outer surface in at least as distinct a manner as the Cretaceous *E. plicifera* Coqu. possesses it.
>
> The length of the specimen in the middle amounts to 15 mm.

EXOGYRA POTOSINA C. and A.

Pl. III, fig. 7; Pl. IV, fig. 7.

Exogyra potosina Castillo and Aguilera, 1895, Faun. Foss. Sierra d. Catorce, p. 3, Pl. II, fig. 9.

Doctor Stanton's collection contains six specimens that are referred to this species. All are larger than the Mexican type specimen fig-

ured by Castillo and Aguilera. Three, of which one closely resembles the example of "*E. subnodosa* Münster," figured in Goldfuss's *Petrafacta germaniæ* (Pl. LXXXVI, fig. 8), are from the foothills west of Malone Mountain, about 2 miles north of the southern end of the mountain, there associated with *Gryphæa mexicana*, *Pinna quadrifrons*, *Pleuromya inconstans*, etc. The three others, representing a variety of more broadly triangular outline, are from the west base of the mountain, only a short distance north of its southern end. The latter station, according to Doctor Stanton's notes, may or may not represent the same horizon as the former and "is certainly several hundred feet above a horizon of *Gryphæa mexicana* and Nerinea."

The specimen, above compared to *E. subnodosa*, has a convexity of about 40 mm. and a lateral profile whose greatest extent, from beak to anterior part of base and extent transverse to the same, are respectively 86 and 55 mm. Corresponding dimensions in one of the larger and broader specimens from the second station above specified are respectively and approximately 39, 93, and 73 mm.

The following is a translation of Castillo and Aguilera's description of *Exogyra potosina:*

Shell elongated, oblique, laterally curved, of semilunar contour. Right[a] valve inflated, its major convexity situated near the umbo, incurved like the shells of Gryphæa; provided with an obtuse crest that traverses the shell in its entire length forming a curve concentric with the anterior margin; beak little free and gently recurved laterally. Left valve operculiform, depressed, and adapted to the concavity which the right valve forms; beak rudimentary. Surface provided with growth-laminæ more marked in the left valve, which is entirely lamellar; on the right valve are perceived two pliciform nodules, obtuse and imperfect, upon the indistinct crest of the shell. Length, 57 mm.

Castillo and Aguilera further describe the shell as intermediate between Exogyra and Gryphæa, noting that it approaches the latter genus both in the general form of the two valves and by preponderance of the vertical over the lateral curvature of the umbonal region. In the Texas specimens, however, at least sometimes, the lateral curvature seems to preponderate.

It is possible that the narrower and broader forms represent two species; but this does not seem probable, and they are here provisionally regarded as mere phases of one.

Exogyra potosina in the Sierra de Catorce, has been recorded only from relatively high beds, which Castillo and Aguilera have considered as Cretaceous. It apparently occurs only high in the Malone district also; but some of its associates in the latter district are apparently identical with the lower occurring *Pleuromya inconstans* (of the Theta and Alamitos); *Gryphæa mexicana* (of the Theta and Jurassic of Oaxaca); *Pecten insutus*, *Pinna quadrifrons*, *Lucina*

[a] *Left, of authors generally, who regard the operculiform valve as the right in the inequivalve forms of this genus.*

metrica, and *Astarte malonensis* (*?*) (of the Theta)—forms which are themselves the common associates of *Trigonia calderoni* (Theta and Alamitos); *Astarte microphyes* (Theta and Jurassic of Oaxaca), etc.

SPONDYLIDÆ.

Genus PLICATULA Lamarck.

PLICATULA SPORTELLA sp. n.

Pl. III, figs. 8, 9.

Shell small, well inflated by the convexity of the broadly rounded, somewhat inequilateral and twisted, broadly attached right valve; left valve nearly flat, its margin rather thick; both valves strongly plicated to the correspondingly crenulated margins, the ribs about 10 on each valve; ribs of the left valve with broadly rounded summits, the furrows between them narrow, those of the right valve with narrower, more widely separated summits, and separated by round-bottomed furrows; surface of ribs and furrows on both valves crossed with imbricated growth lines.

Measurements.—Height, 8 mm.; length, 10 mm.; breadth, 5 mm.

Occurrence.—Malone Hills, 1½ miles east of Malone station. The type and only specimen is attached to a shell of *Nerinea goodellii*.

LIMIDÆ.

Genus LIMA Bruguière.

LIMA INTERLINEATA sp. n.

Pl. IV, figs. 5, 6.

Shell small, obliquely oval, the anterior border straight or very slightly convex, the oval being more elongate than that of *Lima crenulicosta* Roemer, and the lateral profile more nearly approaching that of *L. wacoensis* Roemer; the convexity of the valves, however, agreeing more nearly with *crenulicosta*, and the beaks somewhat more elevated than in either of those species; either valve ornamented with about 22 radiating ribs; the ribs tectiform, having two faces that meet at an angle considerably greater than a right angle; the ribs separated by intervals about as wide as themselves, the middle of each interval marked by a raised line, or, in the case of a few of the posterior intervals, by two to three such lines. It belongs to the subgenus Radula.

Measurements.—Length and breadth of the oval, respectively, 16 and 12 mm.

Occurrence.—Represented by a right valve and several fragments from locality 1½ miles east of Malone station, and, of Doctor Stanton's collecting at same locality, by a left valve with moderately

prominent anterior ear. Doctor Stanton also obtained a fragment from about a mile south-southeast of Finlay station.

LIMA (CTENOSTREON) RIOGRANDENSIS sp. n.

Pl. V, fig. 4.

Shell large and thick, equivalve, somewhat inequilateral, or obliquely round-oval (the base swung somewhat forward), ventricose, anteriorly gaping, radially large-ribbed; ribs broad and low-convex, about 11 or 12 in number on each valve, separated by flat-concave intervals about as broad as themselves; the surface marked with sinuous-concentric growth lines and coarse, laminated imbrications which present convexities upward and downward on the ribs and intervals respectively, the laminated imbrications in places thickened so as to nearly fill the shallow intervals. The ears of the type are broken off. The presence of a byssal sinus is indicated by the direction of the growth lines on the basal remnant of the anterior ear.

Measurements.—Height about 125 mm.; length about the same; breadth, 80.5 mm. The thickness of the shell varies from about 7 mm. on the basal slope to about 13 mm. in the dorsal region.

Occurrence.—Only the single type specimen is known. This was found on the upper part of the Theta outcrop, 1½ miles east of Malone station, associated with specimens of *Trigonia vyschetzkii*, *Astarte malonensis*, etc.

The species seems to considerably exceed in size *Ct. proboscidea* Sby., of the Oxford. The only Ctenostreon that has hitherto been known from North American rocks is an undescribed species reported by Hyatt from the lower Jurassic of Taylorsville, Cal.

PECTINIDÆ.

Genus PECTEN Klein.

PECTEN (CAMPTONECTES) INSUTUS sp. n.

Pl. IV, figs. 11, 12.

Shell pyramidal-subcircular, somewhat inequilateral, with greater anterior than posterior extent, inequivalve; left valve having a fair degree of convexity; right valve flattish-convex; beaks rather pointed, not rounded in well-preserved specimens, the right one but slightly inflated; anterior straight or slightly concave and posterior usually slightly convex (sometimes in part incipiently concave); dorsal margins of body of either valve making a right angle, or often considerably less than a right angle, with each other; anterior ear large, its hinge, or crest line, about twice as long as that of the posterior ear, and its anterior margin reaching about three-fourths as far

in advance of the beaks as does the anterior margin of the valve itself, its byssal sinus angular or subangular; surface of both valves ornamented with numerous fine, closely set, rounded to flattened, radial, linear costellæ, separated by narrower, serially punctate, striæform grooves, and crossed by concentric growth lines, of which some at irregular intervals are more or less strongly imbricated; punctations commonly approaching the form of a circumflex accent, sometimes appearing dot-like, very closely ranked.

Measurements.—Height, 39 mm.; length, 34 mm.; breadth, 10 mm. (right valve 3, left 7).

Occurrence.—About 50 specimens were collected, in the Malone Hills, 1½ miles east of Malone station, the species ranging nearly throughout the fossiliferous Theta there exposed; in foothills about 1 and 2 miles a little south of east from Finlay station; at a point about 2 miles west of Malone station; about three-quarters of a mile farther south (all of the four last-named localities representing the same or nearly the same horizon, No. 13 of Doctor Stanton's Malone Mountain section); and at the anticline in the east slope of Malone Mountain, nearly a mile north of its southern end.

Before obtaining a copy of Felix and Lenk's Beiträge zur Geologie und Palaeontologie der Republik Mexico I had characterized and named in manuscript the above-described common Malone fossil, giving it the specific name *insutus*, in allusion to the peculiar stitched appearance of the seams between the ribs. Its ornamentation closely resembles that of the *Lima comatulicosta*, described in that work, from the upper Jurassic of Mexico. It differs, however, in several respects from that form, as described and figured by Doctor Felix.[a] It is provided with ample ears, of which the anterior is several times the larger; it is inequivalve; its beaks, instead of being rounded, as described and figured by Doctor Felix in his *Lima comatulicosta*, are, when perfectly preserved, rather pointed; and, finally, its outline is less obliquely or anteriorly elongated, sometimes even approaching in the body of the valves an equilateral or circular outline with a pyramidal summit, though usually rather oblique and somewhat elevated.

The break possibly indicated at the position for an ear in fig. 5 (loc. cit.) of *Lima comatulicosta*, the apparent identity of the costal and intercostal ornamentation of the Malone Pecten with that shown in figs. 1, 1a, 3, 3a of the Cerro de Titania shell, and the fact that, unless the *Pecten insutus* be it, the *Lima comatulicosta* is not known from the Malone district, while its appearance there might reasonably be expected (since at least two[b] of the seven lamellibranchs described by Doctor Felix from the Upper Jurassic of the Cerro de Titania

[a] Beiträge, etc., in Palaeontographica, vol. 37, p. 178, Pl. XXVII, figs. 1, 1a, 3, 3a, 5.
[b] *Exogyra subplicifera* and *Gryphæa mexicana*.

have been found to be common to both localities), are circumstances which at one time led me to regard the alleged Lima as probably identical with the common Pecten of Malone. But that the differences of form are considerable, as above shown; that Doctor Felix gives two figures of *Lima comatulicosta* which agree essentially with each other in all respects in which either differs from *Pecten insutus;* that he compares his fossil with a European species of Lima[a] from the coral rag, and that the peculiar intercostal punctation is known to occur both in Lima and in Pecten, are considerations in view of which the assumption that the Mexican fossil has been wrongly referred to Lima is not warranted.

The radially ornamented outer layer of this shell rapidly weathers off, leaving a shiny black surface, so that sometimes the shell appears smooth or bears only subdued concentric markings.

The specimen figured represents the more circular phase of the species and shows the beaks less pointed than they appear in most examples.

AVICULIDÆ.

Genus GERVILLIA Defrance.

GERVILLIA CORRUGATA sp. n.

Pl. IV, figs. 8–10.

Shell inequivalve, very inequilateral, obliquely elongated and curved; hinge provided with several cartilage-pits, the one anterior to the beaks being relatively small; the left valve crescentic as viewed from above, sigmoid as viewed from without, its beak curved forward, inward, and downward, its postero-basal part curved backward, upward, and inward; the right valve (including beak) flattened, its posterior umbonal slope monoclinally angulated, the steep and narrow post-umbonal slope, separating the anterior, anteroposteriorly flat-convex, proximo-distally flat or slightly concave main part of the valve from the relatively depressed posterior wing; anterior wing small or of moderate size, that of the left valve a little contorted, posterior wing rather large, its angle drawn out posteriorly to a point, owing to the strong emargination of its posterior border; umbo of left valve radially corrugated, the adjoining part of the left posterior wing similarly ornamented on a smaller scale, remainder of left and the right valve marked with ordinary growth-lines.

Measurements.—Height,[b] 25 mm.; length, 38 mm.; breath, 12 mm. Portions of several large specimens indicate at least twice these dimensions.

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[a] *L. comatula* Buvignier.

[b] *Height and length* taken as usual, perpendicular and parallel to the hinge-line.

Occurrence.—As yet known only from the Malone Hills, 1½ miles east of Malone station, and only moderately common in the lower part of the Theta beds of that locality, occuring with several of the smaller species of Gastropoda. *Gryphæa mexicana*, which ranges much higher, is also one of its commoner associated fossils. Twenty-three imperfect specimens and fragments were collected.

Gervillia cinderella sp. n.

Pl. V, fig. 1.

Shell subequivalve, moderately inflated, somewhat flattened on the flank, falciform, the basal region being much produced posteriorly, its terminal part tapering; basal margin long, straight, convex; posterior border concave; flank-region limited supero-posteriorly and in part anteriorly by an abruptly rounded shoulder, the surface being drawn steeply in to the base of the wing; posterior shoulder continuous from the beak to the upper part of the posteriorly produced basal region, its axis gently curved with concavity looking upward and backward; anterior wing inflated above, concave and more distinct from the body of the valve below; posterior wing large, falcate (?) (largely broken off in the type), surface bearing delicate concentric growth lines.

Measurements.—Height, 32 (plus several) mm.; length, about (probably a little more than) 57 mm.; breadth, 19 mm.

Occurrence.—One specimen, wanting the cardinal region, was found by Doctor Stanton in the horizon of the broader phase of *Exogyra potosina* at the west base of Malone Mountain, a short distance north of the southern end.

Gervillia ? riograndensis sp. n.

Pl. V, figs. 2, 3.

Another species of lamellibranch, here provisionally referred to Gervillia, was found at the west base of Malone Mountain, associated with *G. cinderella*. It is represented by a cast, of which considerable of the upper posterior region has been removed by weathering, and which bears fragments of the shell of the left valve. The form is less elongate and more compressed than that of *G. cinderella;* the anterior border is concave, the ventral border slightly so, the adjoining lower part of the flanks being slightly hollow, owing to the strong compression of the ventral region. As compared with *G. cinderella*, the antero-ventral border is more prominent and regularly rounded. The shoulder separating the flank from the posterior wing appears, from the cast of part of it, to have been much more gently molded, and this wing seems to have had much greater development in its lower part; surface, as impressed on the mold of a shell fragment, marked with

fine growth lines, of which some, occurring at short subregular intervals on the distal parts, are more strongly imbricated than others.

Measurements.—Height, about 40 mm.; length, 38 mm. (plus 5?); breadth, 17 mm.

Occurrence.—Known only by the above-described specimen, associated with *Gervillia cinderella*, *Exogyra potosina*, *Pleuromya inconstans*, etc.

MYTILIDÆ.

Genus MYTILUS (Linn.) Brug.

MYTILUS NUNTIUS sp. n.

Pl. VI, figs. 4, 5.

Shell small, equivalve (or slightly tortuous-inequivalve?), rather compressed, the right or left profile arched cuneate-oblong, considerably less attenuated anteriorly than that of the somewhat similarly proportioned recent species, *Mytilus afer* Gmelin, the angle made by the anterior margins of the cast being about three-fourths of a right angle; beaks terminal, subacute, gradually and moderately deflected upward, directed much more forward than upward; valves apparently smooth or marked only with concentric growth lines.

Measurements.—Length (oblique) of lateral profile, 21 mm.; breadth of same, 10 mm.; breadth of shell, about 6 mm.

Occurrence.—A single well-preserved cast, bearing thin remnants of the shell, was found among the lower occurring fossils (*Gervillia corrugata*, *Pleurotomaria circumtrunca*, etc.) of the Theta 1½ miles east of Malone station. A form without trace of shell, observed on the matrix of a *Trigonia vyschetzkii* from the same locality, probably represents a valve of the same Mytilus and indicates for it a somewhat larger size.

Though the longitudinal axis of this shell is arcuate, the arching is so gentle that the outline approaches that of the straighter-profiled *Mytilus afer*, as figured by Tryon,[a] more than one of such strongly curved forms as *sublævis*, *eduliformis*, and *decussatus*.

Genus MODIOLA Lamarck.

MODIOLA MALONIANA sp. n.

Pl. VI, figs. 1, 2.

Shell of moderate size in its genus, oblong-trapezoid, gently arched, broadest near the middle, the anterior and posterior regions rather narrow and elevated, the height being greatest at or in advance of the posterior fourth; beaks small and only moderately elevated above the hinge line, placed close together, nearly or quite in contact anteriorly, their dorsal summits forming rather narrow longitudinal ridges from

[a] Struct. and Syst. Conchol.

either of which there proceeds to the posterior part of the basal margin a low, broadly rounded, umbonal swell, below which in the intermediate region the flanks are concave; surface nearly plain, marked only with ordinary growth lines, some of which are imbricated.

Measurements.—Height across umbonal region, 11 mm.; same at highest section of the shell, 12.5 mm.; length, 37.5 mm.; breadth, 11 mm. Another example attains a length of 43 mm.

Occurrence.—The type is from locality 1½ miles east of Malone station, which has yielded two other specimens. I have found a single example also, associated with *Pleuromya inconstans*, *Astarte malonensis*, *Exogyra subplicifera?*, *Gryphæa mexicana*, and *Serpula gordialis*, at the eastern base of Malone Mountain, in the transverse anticline 1 mile from its southern end, just above conglomerates. Two additional specimens were obtained by Doctor Stanton, one from the anticline just mentioned and one from about 1 mile east of Finlay station.

MODIOLA GENICULATA sp. n.

Pl. VI, fig. 3.

Shell small among its congeners, much shorter and higher relative to its breadth than *M. maloniana*, geniculate-trapezoid, the vertically expanded posterior half of the shell being rather suddenly deflected downward and backward so that its axis makes an angle of about 45° with the horizontal cardinal border of the vertically smaller anterior half; breadth less than the height, greatest about the middle; beaks moderately raised, little inflated; flanks concave in the mid region below the umbonal convexity; surface apparently marked only with the ordinary growth lines.

Measurements.—Height, 16 mm.; height of section across middle, 12.5 mm.; length, 25.5 mm.; breadth, estimated from convexity of one valve, 10 mm.

Occurrence.—A single left valve was collected by Doctor Stanton about 1 mile east of Finlay station.

PINNIDÆ.

Genus PINNA Linnæus.

PINNA QUADRIFRONS sp. n.

Pl. VII, figs. 1–8.

Shell of medium size in its genus, elongate-cuneate; anterior region inflated, in cross section bicuspidately round-oval to quadrate-oval; posterior region rather compressed, in cross section nearly rhombic; valves meeting by their ventral margins at an acute and more or less compressed or cariniform angle and by their dorsal margins at a somewhat similar angle; from their anterior, more convex part, be-

coming at first feebly and then, on the middle and posterior region, strongly and abruptly obtuse-angulated along a radial line a little above the middle, so that either valve presents two slopes—a dorsal, which is flat or in part feebly concave, and a somewhat wider ventral, which retains some convexity even on the posterior part; dorsal slope of either valve ornamented with 10 to 15 compressed and gently elevated radial costellæ, which are separated by intervals wider than themselves and obliquely scored by numerous growth lines that give the costellæ a more or less granulated or crenulated appearance; ventral slope marked only with strong, pliciform, for the most part very oblique growth lines. The summit of the supra-median angle is the locus of a linear hingelike plait, or gore, by whose ready erosion the valves are often cleft, especially along the middle and posterior region, each into two valvelike segments, so that broken specimens which include only that region appear not only tetragonal and quadrilateral, but also quadrivalvate.

Measurements.—Height (across larger end), 56 mm.; breadth (across same), 30 mm.; length, 240 mm.; all approximate.

Occurrence.—One and a half miles east of Malone station. This is one of the most abundant fossils of the Theta subdivision in that locality and ranges nearly throughout the known fossiliferous thickness of it. It usually occurs in sections varying in size from less than 1 inch to 4 or 5 inches long, of which about 80 were here obobtained. Some have been subjected to pressure in such a manner as to make them nearly square in cross section. Doctor Stanton also obtained several on the west side of Malone Mountain, as follows: One in No. 25 of his Malone Mountain section, 2 miles south of west Malone station; 2 from a foothill about 2 miles northwest of the southern end of the mountain, and 6 from the west base of the mountain, a short distance north of its southern end. Part of those (casts) from the last-named locality are more than usually compressed, rapidly expanded, and somewhat curved, and at first sight suggest a distinct species or variety; but others are of intermediate form and some bear shell remnants with seemingly characteristic *quadrifrons* ornamentation, so that, while individual variation may have played a part, the exceptional form should probably be attributed chiefly, if not wholly, to the distortive influence of the orogenic forces that have acted upon the matrix containing them.

ARCIDÆ.

Genus ARCA Linnæus.

ARCA TAFFII sp. n.

Pl. VI, figs. 7, 8.

Shell small, ventricose, broader than high, of moderate length; *beaks strongly* arched, inrolled, and brought into contact; posterior

slope angulated and strongly flattened (radially costate?); anterior slope a little excavated on the upper part, separated from the outer slope by a rounded shoulder, ornamented with a few strongly elevated radial costæ separated by comparatively wide intervals, in each of which is a feebler linear costella; outer slope flattened, radially costate, becoming closely cancellated on the middle and strongly so on the ventral part; ventral margin straight, not crenulated. There are 20 of the costæ on the outer slope, small, with their rounded summits subgranulated by the cancellation, and separated by intervals of about their own width. On the summit of the umbo the axis of flattening is inclined forward.

Measurements.—Height, 10.5 mm.; length, 19 mm.; breadth, 12 mm.

Occurrence.—One and a half miles east of Malone station; represented by only one example.

The ornamentation of the posterior slope is concealed in the type specimen. A radiately costate ornamentation upon it is inferred from the fact that the species seems to agree subgenerically with Gray's Calloarca as described and figured in Tryon's Structural and Systematic Conchology. A slight inequality of the valves in the umbonal region is doubtless a distortion due to stratigraphical disturbance. The specimen does not disclose the characters of either the hinge or the ligamental area.

ARCA? DUMBLI sp. n.

Pl. VI, fig. 6.

Shell small, only moderately inflated, rather elongate-trapezoidal, the anterior side short and subvertically truncate, the posterior long and obliquely truncate; the base gently convex; the moderately elevated beaks situated at the rear limit of the anterior third; anterior slope small, concave, wing-like, with supero-anterior corner nearly a right angle, separated from the outer slope by a posterior umbonal angulation, which becomes obsolete distally; posterior slope concave, separated from the outer by a strong, proximally subacute, distally obtuse shoulder-like angulation, the two apposed concave slopes forming together a sort of wing with obtuse corner; the anterior slope ornamented with a few narrow, distally obtuse radial folds, the outer slope with ordinary and strong concentric growth-lines, radial lines, if originally present here, having been feeble and obliterated by weathering in the types, the posterior slope and the summit of its limiting angle having numerous radiating raised lines and striæ.

Measurements.—Height, 16.5 mm.; length, 30 mm.; breadth, about 12 mm.

Occurrence.—One and a half miles east of Malone station; represented by 5 specimens.

The hinge characters of this shell are unknown. While the general form permits little doubt that it is one of the Arcidæ, there is less certainty of its generic position, and it is placed only provisionally under Arca.

The species is named for Mr. E. T. Dumble, late State geologist of Texas.

Genus CUCULLÆA Lamarck.

CUCULLÆA? TEXTICOSTATA sp. n.

Pl. VI, figs. 9, 10.

Shell ventricose, short, subtriangular, somewhat pointed inferoposteriorly, rounded anteriorly, the posterior slope flattened and making an angle with the outer slope; beaks well inflated and elevated; entire surface marked in a crowded manner with radiating linear costellæ and in large part with erect concentric lines of imbrication, of which the latter are the finer and more crowded (seen to advantage only when magnified), and the former the more conspicuous and more persistent under weathering. A considerable part of the surface when magnified appears woven, like cloth or miniature basket work, except for the alternating arrangement seen in the latter. This woven ornamentation resembles that seen in *Arca taffii*, the radial costellæ being, however, much finer and more numerous than in that anteriorly and posteriorly otherwise ornate and altogether differently shaped arcid.

Measurements.—Height, about 29 or 30 mm. (?); length, 34 mm.; breadth, 24 mm.

Occurrence.—One specimen and a fragment of a second; 1½ miles east of Malone station.

In the absence of any knowledge of the hinge of this shell it is not possible to be sure whether it is a Cucullæa or an Arca. The ornamentation—primarily radial and secondarily cancellated—is of a type more common in the latter genus; but the species is put provisionally in Cucullæa, under the subgenus Trigonarca, on account of its triangular form.

CUCULLÆA TRANSPECOSENSIS Cragin.

Cucullæa transpecosensis Cragin, 1893; Fourth Ann. Rept. Geol. Survey Texas, pt. 2, p. 175.

The genus Cucullæa is not represented by abundance of individuals in any of its species in the rocks of the Malone formation in Texas, and so rare is the massive and ventricose *C. transpecosensis* that, despite careful collecting for many days at the locality which yielded Messrs. von Streeruwitz and Wyschetzki the type, the latter still *remains the only* specimen known of this species.

As it has not been practicable to restudy the type, the original account of the species is here reproduced, which is as follows:

Shell large and thick, ventricose (subrhomboidal?); beaks large, remote from the anterior extremity, their summits very obtuse as viewed from the side or from above, their apices less compressed and less free than in *C. terminalis* or *C. gratioti*;[a] anterior dorsal border prominent and compressed, subaliform, the surface included between it and the [anterior [b]] line of the beaks being ornamented with raised radial lines, posterior dorsal angle (apparently) shorter and lower than the anterior, posterior umbonal slope prominently angulated, the angulation succeeded on the inner side by a pronounced sulcus, which is in turn limited on its inner side by another angulation less prominent than the first: hinge-area broad, divaricate-grooved; anterior lateral denticles four (and one rudimentary), long, strong, and horizontal, their abruptly deflected inner termination being relatively very short. Mesial and posterior denticles unknown.

Occurrence.—Collected by Mr. von Streeruwitz about 1 mile northeast[c] of Malone, El Paso County, with *Venus maloncnsis*[d] and other forms, as mentioned under that species. Comanche series.[e]

In size this shell apparently exceeds the other known species of Cucullæa from the Comanche series of Texas.

CUCULLEA CATORCENSIS C. and A.

Cucullæa (*Trigonarca*) *catorcensis* Castillo and Aguilera, 1895, Bol. Com. Geol. Mex., No. 1, p. 5, Pl. IV, figs. 1, 4, and 5.

Two small Cucullæa casts, of medium ventricosity, obtained below the Iota conglomerates, 1½ miles east of Malone station, and two from above similar conglomerates in the eastern base of Malone Mountain, in the anticline about 1 mile north of its southern end, are referred to the young of this species.

The following is a translation of Castillo and Aguilera's description of *Cucullæa catorcensis*, as given (loc. cit.) in their "Fauna Fosil de la Sierra de Catorce:"

Shell bulky, very convex, of quite variable contour, oval in the young examples, subquadrangular in those which are more developed, and subtrapezoidal in the adults. Beaks broad, very prominent and little removed from one another, situated in the anterior third and nearly terminal in the adult examples, provided with a carina on the anal side. Buccal region very much more short than the anal, rounded on the extremity, a little excavated near the cardinal border

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[a] *C. terminalis* Con. and *C. gratioti* Hill, of the Comanche Cretaceous.

[b] Reads "posterior," by error, in the original.

[c] The same locality is herein generally called "1½ miles east of Malone station," and is perhaps a little short of the latter distance, so far as occurrence of the larger number of the fossils is concerned. I have understood that all of the fossils obtained from this spot in 1890 were actually collected by Mr. Wyschetzki; and if so, the name of Mr. von Streeruwitz was probably put on the label in view of his having been in charge of the trans-Pecos division of the Texas survey.

[d] *Astarte maloncnsis* of the present writing.

[e] For explanation of the manner in which the few fossils known from this locality in 1893 were at that time placed in the Comanche series, see Introduction. Instead of "Comanche series," read Malone formation.

with which it forms an acute angle. Anal region obliquely truncate on its extremity, excavated or concave in the vicinity of the beaks, limited by a well-marked carina which traverses the shell from the beak down to the posterior extremity at its junction with the inferior border of the shell; the carina is quite acute near the beak and becomes more obtuse in proportion as it recedes from it; the umbonal region, thus circumscribed by the umbonal crest, forms a sort of corselet, quite marked and excavated. Middle region of the shell convex and in the form of a triangle limited by the anal crest and the other less developed which separates it from the buccal region; the major convexity of the shell is just adjoining the anal crest and near the beaks. Ligamental area not very much excavated and of regular dimensions. Cardinal border straight, in some specimens nearly as long as the shell, but in others much shorter; anterior border obliquely rounded; inferior border nearly straight and parallel to the cardinal border, joining by means of a curve with the posterior border, which is oblique, slightly curved, and in the young forms nearly parallel to the anterior border. Surface of the shell provided with concentric lines of growth which have suffered interruptions and constitute more or less prominent corrugations.

Length, 60.62 mm.; breadth with relation to the length, 0.58.

Locality: Arroyo de Alamitos, on the Alamitos rancho, in the Sierra de Catorce.

By breadth ("ancho") in the above is meant the dorso-ventral dimension called height by some writers. The lateral breadth, called thickness ("espesor") in the "Fauna Fosil," is not stated.

The massiveness of this shell, its ventricose form, its broad beaks, and the demarcation of the middle from the posterior umbonal slope by a cariniform angulation, are features which might seem to indecate that *Cucullæa catorcensis* should be referred to the Texan *C. transpecosensis;* but the very prominent and subterminal beaks, and (so far as the description indicates) the absence of a second, or inner, angulation on the posterior corselet and of raised radial lines on the anterior umbonal slope in *C. catorcensis*, appears to sufficiently distinguish the latter as a valid species.

CUCULLÆA CASTILLOI sp. n.

Pl. VI, figs. 11, 12.

Shell of moderate size in the genus, short-trapezoidal; ventricosity of medium degree, greatest considerably above the middle; anterior side short, rounded; posterior side straight, obliquely truncate; base gently convex; the infero-posterior part of the shell somewhat pointed, owing to a prominent, rapidly rounded shoulder that runs from either beak to the junction of the ventral with the posterior border, separating the outer convex slope from the posterior slope, which latter is strongly and concavely depressed, being strongly inflected near the shoulder and turning outward again about midway of its extension toward the posterior border, to form a prominent

and sharp keel by union with the corresponding border region of the opposite valve; anterior umbonal slope only feebly angulated or shouldered; beaks narrow, high-arched, approximated, placed slightly in advance of the middle third; flank region marked with concentric growth lines; posterior slope finely and closely striate.

Measurements.—Height, 39 mm.; length, about 48 mm.; breadth, about 34 mm.

Occurrence.—Two examples were collected by Doctor Stanton in foothills at the northwest end of Malone Mountain, about 2 miles east-southeast of Finlay station. Neither shows the ornamentation of the anterior slope.

The species is named for the late Prof. Antonio del Castillo, founder-director of the Geological Institute of Mexico.

NUCULIDÆ.

Genus LEDA Schumacher.

LEDA? NAVICULA sp. n.

Pl. VI, fig. 13.

Shell fairly well inflated, elongate-ovate, anteriorly not shortened, posteriorly produced and gradually narrowed or subrostrate; the anterior subhorizontal and posterior gently declined parts of the dorsal side each forming a small concavity adjoining the beak, anterior side rounded, base long and straight-convex for the greater part, its posterior part ascending obliquely; beak small and little salient, placed a little back of the anterior third.

Measurements.—Height, 11.5 mm.; length, 25 mm.; breadth, about 10 mm.

Occurrence.—A cast of a left valve was found embedded in the rock fragment bearing one of the specimens of *Unicardium semirotundum* collected by Doctor Stanton at the anticline on the east slope of Malone Mountain about 1 mile north of its southern end.

A cast of a small, posteriorly produced lamellibranch, which was supposed in the field to be one of the Nuculidæ and which may have been a Leda, was observed in Theta a mile and a half east of Malone station. It was accidentally destroyed in attempting to remove it from the matrix. A rough sketch of it, preserved in my notes, indicates a shell similar in form to that above described, but smaller. It may be referred to *Leda? navicula*, but is represented as having the margins crenulated, while this character, if it belonged to the latter species, can not be distinguished in the type as preserved.

TRIGONIIDÆ.

Genus TRIGONIA Brug.

TRIGONIA VYSCHETZKII Cragin.

Pl. VIII, figs 1, 2; Pl. IX, figs. 1–3.

Trigonia vyschetzkii Cragin, 1893, Fourth Ann. Rept. Geol. Survey Tex., pt. 2, p. 215; and, 1897, Jour. Geol., vol. 5, No. 8, pp. 816, 817.

Cf. *Trigonia sologureni* Felix, 1891, Beitr. Geol. u. Pal. Mex., pt. 3, p. 179, Pl. XXVII, figs. 2, 2a.

Shell large, of moderate convexity, transversely subquadrate; postero-dorsal side straight; anterior and posterior sides truncate; base gently curved; beaks only moderately arched; area flattened, occupying about one-fourth of the valve, bordered above and below by a tuberculated ridge or angulation, and traversed by a median groove which is accompanied by a third such ridge less developed than those of the border, a large distal part of it obliquely crossed in most instances by numerous strong, more or less irregular and interrupted folds, or ornamented on the proximal part with rows of tubercles by whose increasing confluence on the intermediate and distal parts the folds are produced, the tubercular endings of these folds usually descending across the entire outer slope of the bounding ridge, and in some cases even passing a little beyond it; escutcheon depressed, crossed with a series of transverse, somewhat oblique, straight, or in part slightly curved, tubercular costellæ; preäreal surface ornamented with about 15 gently curved nodose costæ, which are subvertical near the infraäreal ridge and make with the latter at first an acute and then approximately a right angle, descending for the most part obliquely, though steeply, to the base; the costæ attenuated and simpler near the area, becoming resolved into irregularly more and more robust nodes as they recede from it, the posterior and intermediate costæ thus enlarging throughout, while a few of the shorter anterior ones, turning forward at their lower ends across the flattened front of the shell, are here again reduced to nearly simple ridges which dwindle and disappear before reaching the valve margin; nodes mostly close ranked, commonly 12 to 16 on the larger ribs of adult shells, rounded, often more or less compressed so as to trend with the growth lines, a rib often having a single very large node near the basal margin of the valve especially thus elongated; intervals between the costæ coarsely concentrically striate. The separation of the siphonal currents is indicated, as in the Clavellatæ and Scabræ, by a ridge on the interior of the shell. The ornamentation shows considerable mutability, and a variety occurs in which the entire area is covered with small compressed tubercles. In one specimen the *costellæ* of the escutcheon are simple.

Measurements.—Approximately, height, 76 mm.; length, 87 mm.; breadth, 50 mm. Two very young examples have these dimensions, respectively, 16, 17, 10, and 25, 27, 15 mm.

Occurrence.—So far as the collections show, this Trigonia does not occur in the Malone district, except in the Malone Hills and in the Theta subdivision of the Trio section. In these, however, 1½ miles east of Malone station, it becomes numerically one of the commonest fossils of the Malone formation. In the rich collecting tract there, on the basal slopes of the Truncate mound and the southeast base of hill *C* of the Trio, and especially on the western basal slope of the former, it was found by scores, in one or two places being agglomerated in beds, mingled more or less with other fossils. Between 75 and 100 specimens of it are represented from this tract. But if the shells of other Malone fossils, as here preserved, prove fragile under the rigorous temperature changes of a plateau climate, that of *Trigonia vyschetzkii* is so especially, and of the large number collected many are in half-released fragments, and comparatively few make even tolerably fair cabinet specimens. I also found this fossil about half a mile west-northwest of this locality on the south side of the flat saddle that separates the Trio from the low gypsum-parted ridge which continues the hill range in that direction.

The series of quadrate pits mentioned by Lycett [a] and cited by Steinmann [b] as occurring posteriorly on the interior of the valve near the ventral margin in Quadratæ, is lacking in *T. vyschetzkii.* The form differs from that of the Quadratæ and agrees with that of the Clavellatæ in being considerably longer than high, yet agrees with Quadratæ and differs from Clavellatæ in being quadrilateral instead of subtriangular. In having the escutcheon ornamented and in some—usually slight—tendency which the areal folds manifest to infringe on the general surface below the limiting angle, on the posterior region, the shell agrees with the Quadratæ.

The *T. vyschetzkii* is thus seen to be closely related to the South American *T. transitoria* Steinm., upon which and the related *T. herzogi* Hausmann, of South Africa, Steinmann, in 1882, proposed to add *Pseudo-Quadratæ* [c] to the previously known sections of Trigonia. Its profile is usually less elongate and the ornamentation, especially that of the area and escutcheon, less coarse than in *T. transitoria*, the folds of the area descending the lower slope of the limiting angle, but descending only a little (sometimes not at all) below it on the posterior region.

Normal casts of *Trigonia vyschetzkii* are differently proportioned from that which—from Tlaxiaco, Mexico—Doctor Felix figures as

[a] Mon. Brit. Foss. Trigon., p. 100.
[b] Neues Jahrb. für Mineral., 1882, vol. 1, p. 221.
[c] *Loc. cit.*, pp. 219–228, Pls. VII–IX.

the type of his *T. sologureni*,[a] a shorter, more elevated, and much more ventricose form being indicated for the latter species. But the cast of *T. vyschetzkii*, in one or two of our specimens, somewhat approaches that of *T. sologureni* in form, while several species of fossils are common to Malone and Tlaxiaco; so that it is desirable to compare actual shells of these two species with one another as well as with the shell of *T. transitoria*.

TRIGONIA GOODELLII Cragin.

Pl. X, figs. 1, 2.

Trigonia goodellii Cragin, 1897, Jour. Geol., vol. 5, p. 816.

Shell of about medium size in its genus, produced ovate, ventricose; valves thick; beaks situated near the rear limit of the anterior fourth, low, strongly inflated, in contact, their posterior slope strongly angulated to form the limiting angle of the area; area flattened, nearly plain, having numerous fine oblique growth lines, with a few small folds crossing it near and concentric to the beaks, these folds being continuous of and making an angle with those in front of the area, some low tubercles along the marginal angles, and a faint mesial sulcus; escutcheon bearing only inconspicuous folds which radiate from the ligament, those of the proximal part being nearly transverse to the length of the escutcheon and continuous with those of the corresponding part of the area; general ornamentation consisting of a series of ribs, which on the posterior part of the preäreal surface are large, obtuse, and plain or subtuberculated, separated by round-bottomed valleys of about their own width, and descend almost vertically (the earlier ones more obliquely forward) from the inferior border of the area, increasing in size each to an elbow-like angle, at which they turn abruptly forward, becoming reduced in size to costellæ in front of these elbows and partially resolved each into a series of small tubercles, these costellæ being accompanied each by one or two similar ones in the intervals between them, the costellæ diminishing gradually in size and swinging into the course of ordinary growth lines on the anterior region, and there becoming continuous and like strong reversed imbrications, each presenting its acute and more elevated border dorsad. The series of costal elbows radiates at first downward and then obliquely downward and backward from the beaks.

Measurements.—Height, 42 mm.; length, about 58 to 60 (plus?) mm.; breadth, 35 mm.

[a] Versteinerungen aus dem oberen Jura des Cerro de Titania bei Tlaxiaco im Staat Oaxaca, 1891, Beitr. Geol. u. Pal. Mex., pt. 3, Palaeontographica, vol. 37, p. 179, Pl. XXVII, figs. 2, 2a.

Occurrence.—One and a half miles east of Malone station. Besides the original example which the Messrs. Goodell discovered, and from which the illustration and measurements have been taken, 17 other imperfect specimens and fragments were obtained at this locality, some of them indicating dimensions perhaps a fourth larger than those of the type.

It will be seen from the description that the ornamentation of *T. goodellii* is variable. This, however, is true of most Trigonias, and not least so of those of the section, Undulatæ, to which this species belongs.

None of the Old World Undulatæ known to me corresponds very closely with *T. goodellii.* Several of those from the Great Oölite, which is so rich in Undulatæ, bear more or less resemblance to it; but the strict analogue, if found, may be expected to occur in the Tithonian.

The species was named after the late Mr. Robert Wood Goodell, whose kind services in assisting me to determine the age of the Malone formation I have particularly acknowledged in my article on the "Discovery of marine Jurassic rocks in southwestern Texas," the paper in which the species was first briefly characterized and named.

A Trigonia cast, showing nothing of the ornamentation, but indicating the general form of *T. goodellii*, having still larger dimensions than any of the above, and belonging not improbably to this species, was obtained by Doctor Stanton from conglomerate on the west face and near the top of Malone Mountain. It gives the following measurements: Height, 62 mm.; length, 72 mm.; breadth, 46 mm.

TRIGONIA CALDERONI (C. and A.).

Pl. IX, figs. 4–6.

Goniomya calderoni Castillo and Aguilera, 1895, Bol. Com. Geol. Mex., No. 1, p. 9, Pl. V, figs. 17, 18.

Shell elongate-trapezoid, very inequilateral, moderately inflated, the region of greatest convexity extending from the umbones downward and backward; anterior region relatively short and of considerable height relative to the posterior, the anterior contour rounded: posterior region strongly produced backward and inclined a little upward, gradually and strongly tapered toward its extremity, which is obliquely truncate and looks backward and upward, its flanks more or less flattened; base gently convex below the beaks, ascending thence anteriorly in an easy convex curve and posteriorly slowly in a long and nearly straight line; beaks but moderately elevated, their apices curved inward and somewhat backward and downward; escutcheon rather large and long, plain; area of moderate width, flattened, traversed lengthwise by a mesial groove, and transversely linear-plicate,

the plicules separated by striæ; preäreal surface ornamented with two sets of ribs, of which the anterior ribs are acute, upwardly-imbricate, remote, subhorizontal, with gentle sigmoid flexure, presenting a slight upward convexity below the beaks and a downward one farther forward, and alternately reach the more anterior ribs of the other set; posterior ribs thicker, more obtuse, and more narrowly intervaled than the anterior, nearly straight, and directed steeply downward and backward from the limiting angle of the area, the proximal of these being the more nearly vertical and the distal and independent ones more oblique, the intermediate ones being the longest. Slight irregularities sometimes appear in the course of the anterior ribs, each of which, in one example, bears a small dorsally directed angle at the summit of its infraumbonal convexity.

Measurements.—One of the Texan examples, which has a length of 58 mm., indicates for the shell in part restored, a height of 32 mm. and a breadth of 23 mm., approximately.

Occurrence.—The Malone formation yields this fossil rather sparingly. Eleven specimens and characteristic fragments are represented. Eight of these are from the Malone Hills, 1½ miles east of Malone station; the others were collected about a mile east of Finlay station.

In the character of the preäreal ornamentation, the species presents considerable resemblance to *Trigonia sulcataria* Lamarck, as figured by Lycett on Pls. XXVI and XXVIII of his British Fossil Trigoniæ, a species which has been referred to the Undulatæ, but is shown by Lycett to belong to the Scabræ. The plain escutcheon, however, at once separates *T. calderoni* from the Scabræ, and the same and all of the other external characters refer it to the Undulatæ.

TRIGONIA PROSCABRA sp. n.

Pl. X, figs. 3–6.

Shell small, crescentic-ovate or subsemicircular, the upper border strongly excavated, anteriorly inflated, gradually becoming more compressed toward the posterior extremity; beaks somewhat produced and recurved; escutcheon large, broader than the area, ornamented with rather remote, coarse, but not very strongly elevated, oblique costellæ; area flattened, narrow, transversely linear-plicate, traversed by a mesial depressed line, and bounded both above and below by a row of tubercles, those of the lower row surmounting a distinct limiting ridge and larger than those of the preäreal costæ opposite whose terminations they are placed; the areal plications, though fine and numerous, are mostly separated by intervals wider *than themselves*; preäreal surface denticulate-costate, the denticles

cuneïform, each consisting of a superior, compressed, tuberculiform head and an attenuated cariniform process which dwindles to a point below, crossing the longer and gentler posterior costal slope, but not crossing the fundus of the intercostal valley quite to the base of the comparatively abrupt anterior costal face. The costæ are moderately interspaced, becoming rather widely intervaled when the shell attains the adult size. A small flattened tract formed by the conjoined antero-dorsal margins, is minutely wrinkled transversely to the margins, as the earlier ribs, before reaching the margin, become suddenly reduced and changed to minute linear folds, paralleled in their intervals by similar folds, of which there are two in each interval.

Measurements.—Height, about 30 mm.; length, 36 mm.; breadth, 21 mm. One specimen, represented by a considerable part of a right valve, indicates, with a breadth of about the same or a millimeter less, a height and length 2 or 3 mm. greater. Young examples are relatively shorter, or more elevated, one such example having height 20 mm.; length, 20 mm.; breadth, 14 mm.

Occurrence.—One and a half miles east of Malone station. About 35 specimens are represented, many of them only by fragments. A crushed specimen from this locality has the costal and areal ornamentation exceptionally well preserved and shows an almost spinous prominence of the denticles. A cast, representing the anterior two-thirds of a right valve on which the costæ are indicated as plain undulations, obtained by Doctor Stanton about 1 mile east of Finlay station, is supposed to belong to this species, but may represent *T. præstriata.*

Trigonia proscabra presents points of resemblance especially to two of the sections of its genus, and does not agree entirely with either. It may be regarded as one of the Clavellatæ which, both as to form and preäreal ornamentation, has assumed the habit of a common phase of the Scabræ. In having an ornamented escutcheon it differs from the typical Clavellatæ, though not from the Pseudoquadratæ—which are intermediate between Clavellatæ and Quadratæ. In having the area bounded on each side by a row of tubercles and below by a pronounced limiting ridge it resembles the Clavellatæ.

TRIGONIA PRÆSTRIATA sp. n.

Pl. X, fig. 7.

Shell small, crescentic-ovate, only moderately inflated; area strongly and closely striated in a direction oblique to its length, bounded below by a rather strongly compressed and prominent limiting ridge or angulation; preäreal ribs about 12 or 14 in number, coarse, remote, and strongly elevated, descending divergently and for the most part

more or less vertically, and increasing rather rapidly in size from the limiting angulation to the ventral and anterior borders, about twice as wide as the plain, flattish-concave intervals between them, their summits obtuse and strongly and a little obliquely cross-striated in such a manner that the striation is visible if the ribs are viewed tangentially from in front, but invisible if so viewed from behind.

Measurements.—Height, 21 mm.; length, 30 mm.; breadth, 10 mm.; approximately.

Occurrence.—A single mold, representing the greater part of a right valve in excellent detail, is the type and only known specimen. It was obtained by Doctor Stanton on the east slope of Malone Mountain, near its southern end, 200 or 300 feet above the gypsum bed that there forms the mountain's base. It lacks the escutcheon, the upper part of the area, and the umbonal apex, but the exterior characters of nearly all of the rest of the shell may be readily observed either in the mold or on the gutta-percha squeeze taken from it. The species is referred to the section Scabræ.

TRIGONIA MUNITA sp. n.

Pl. X, figs. 8–11.

Shell ovate-pyramidal, of medium or rather large size among its congeners, moderately ventricose, rather elevated; valves thick; area strongly flattened, separated from the preäreal surface by a very large and prominent, obtuse, somewhat imbricated radial costa, preceded by a furrow, the areal surface being ornamented with two rather strong, not widely separated, cariniform radial costæ, which are separated from each other by an interval that is rather narrow as compared with that between either costa and the corresponding areal border, and several similar but smaller costellæ or rays, there being at least two such rays in the anterior interval; preäreal surface ornamented with (25 to 30?) strongly and rather abruptly elevated concentric ribs, which resemble low walls, terminate almost abruptly at the preäreal furrow, and are in large part only about half as wide as the flattish-concave intervals between them.

Measurements.—These can not be exactly given, owing to the imperfection of the material, but about the following dimensions are apparently indicated in one instance: Height, 70 mm.; length, 75 mm.; breadth, 42 mm. In another the height is about 80 mm.

Occurrence.—Represented by three very imperfect specimens and a number of characteristically ornamented fragments. One of the specimens were obtained by Doctor Stanton near the south end of Malone Mountain, west face, near top, and another west of the mountain, about 2 miles west of Malone station. The remainder of the material is from the locality 1½ miles east of Malone station. All of

the known material represents the adult condition, or at least rather large sizes of the shell, unless the two specimens described under the head of *Trigonia rudicostata* should be interpreted as the young of *T. munita*. This species with the two that follow belongs to the section Costatæ.

TRIGONIA RUDICOSTATA sp. n.

Pl. XI, figs. 1, 2.

Shell small, ovate-pyramidal, nearly straight (slightly convex) on the postero-dorsal, broadly convex on the ventral, and less broadly so on the anterior side, inflation intermediate in degree; beaks situated at rear limit of the anterior fourth, prominent and acute at the compressed and transversely placed summit, excavated on the posterior side, turned inward and somewhat backward; area nearly flat, shallow-concave on its proximal part, wide, making with the preäreal surface an angle greater than a right angle, and separated from it by a compressed, prominent radial costa, which is larger than any other costa of the shell, the area posterior to this costa being ornamented with 4 or 5 similar but narrower and smaller rays, between each two of which are 3 to 5 still smaller, strongly elevated, linear rays or costellæ, the intercostellar spaces being at least as wide as, or for the most part wider than, the rays themselves, preäreal surface ornamented with about 25 strongly elevated, round-topped ribs which parallel the basal margin and are mostly slightly wider than the intervals between them. There are 7 of the horizontal or concentric ribs in the lower half in one specimen and 10 on the lower 10 mm. in another.

Measurements.—Height, 23 mm.; length, 27 mm.; breadth, 16.5 mm.

Occurrence.—The two specimens in the collections were obtained 1½ miles east of Malone station.

Although the material thus far available for study indicates between *T. rudicostata* and *T. munita* differences of both radial and concentric ornamentation too marked to be ignored, it is quite possible that new material from localities known or yet to be discovered may show that these differences are due to conditions of age or individual variation; for it is noteworthy that, except the types of *T. rudicostata*, no Costatæ even approaching what we should predicate for the young of *T. munita*, have been found.

TRIGONIA CONFERTICOSTATA sp. n.

Pl. XI, fig. 3.

Shell small, subtriangular, of the section Costatæ, apparently more elevated than *T. rudicostata;* posterior area costellate with

linear rays, of which there are 5 to 7 smaller in the shallow-concave interval between each two of the larger; a large radial rib anteriorly limiting the area; preäreal surface ornamented with about 40 strongly elevated concentric ribs which are much finer than those of *T. rudicostata* and between one and a half times and twice as numerous, and are separated by intervals prevailingly narrower than themselves. In a specimen smaller than the largest, but which nearly corresponds in size with the type of *T. rudicostata*, there are 15 ribs on the lower 10 mm. of height of the valve, as compared with 10 on the same part of the height in the said example of *T. rudicostata*. As against 7 ribs included in the lower half of *T. rudicostata*, there are in one specimen of *conferticostata* not less than 12, and in another 14 in the corresponding half.

Measurements.—The dimensions can not be accurately given. The height of the largest specimen is about 33 mm. An apparently crushed and abnormally elongated specimen gives approximately: Height, 25 mm.; length, 29 mm.; breadth, 15 mm.

Occurrence.—The species is represented by one nearly complete shell, two considerable portions of valves, and a few fragments; from locality 1½ miles east of Malone station. The shell fragment collected in 1895 by the Messrs. Goodell, and which I referred to in volume 5 of the Journal of Geology (p. 817) as "possibly a Trigonia of the section Costatæ," is of this species.

ASTARTIDÆ.

Genus ASTARTE Sowerby.

ASTARTE BREVIACOLA sp. n.

Pl. XI, fig. 4.

Cf. *Astarte microphyes* Felix, 1891, Beitr. Geol. u. Pal. Mex., pt. 3, p. 179, Pl. XXVII, fig. 31.

The locality 1½ miles east of Malone station yielded frequent examples of this fossil. They agree fairly well with Doctor Felix's description of *Astarte microphyes*, but not with his figure. As regards the peculiar disposition of the ribs which is given for *A. microphyes*, the tendency to posterior angular bending is well shown in most specimens of the Malone Astarte, but a tendency to anterior angular bending is little or in some cases apparently not at all expressed. If the Cerro de Titania and the Malone specimens are referable to one and the same species, *microphyes*, as seems hardly possible, the form of that species is not quite correctly shown in the original figure, as the anterior part of the dorsal line, instead of sloping like the posterior part, is strongly excavated just in front of the beaks in all of the Malone specimens in which this part of the

shell is shown. The triangular-ovate to quinquelateral outline presents dorsally a nearly straight incline back of the beaks and is strongly excavated in front of them; has a long, gently convex base, and is posteriorly or infero-posteriorly truncate, and narrowly rounded anteriorly. The shell is quite strongly compressed, and the ribs of either valve reach 11 in number. The ribs are coarse, strongly elevated, gently compressed, and separated by round-bottomed intervals a little wider than themselves. Of more than 60 specimens collected from east of Malone, a single one, among the young examples, is quite ventricose, gapes slightly in the interval between two of the subdistal ribs, and exposes there a double and interlocking set of strong denticles like those of the internal margins of the adult shell.

Measurements.—The specimen figured has the following dimensions: Height, 10 mm.; length, 14 mm.; breadth, 4 mm. In less perfect examples a height of 12 mm. and a length of 16 mm. are indicated.

ASTARTE MALONENSIS Cragin.

Pl. XI, figs. 10, 11; Pl. XII, figs. 1–3.

Venus malonensis Cragin, 1893, Fourth Ann. Rept. Geol. Survey Texas, pt. 2, p. 216, Pl. XXXV, figs. 1 and 2; and Jour. Geol., vol. 5, p. 817.

Shell rather large, thick-valved, moderately ventricose, or sometimes slightly compressed, inequilateral, broadly and variably subovate; the dorsal side flattish-convex behind the beaks and excavated in advance of them; the anterior side rounded or slightly subtruncate from being a little prominent in its upper part; the posterior side rather narrowly convex; the base broadly convex; beaks only moderately elevated, approximate, their summits varying from subcentral to a position just back of the anterior third; lunule and escutcheon deeply and abruptly impressed, especially the former, which is narrow-cordate; cardinal teeth 2–2, unstriated, the central of the right valve being much larger than the anterior and the posterior of the left valve being larger than the central;[a] a posterior remote, horizontal, pliciform lateral tooth in either valve fitting into a corresponding groove in the other; pallial line sinuate, its impress on the best-preserved casts crossed by faint radial plications; pallial sinus ample, its anterior and posterior limbs, respectively, subvertical and subhorizontal (the latter a little ascending), its fundus obtuse; valve margins crenulated within; shell ornamented with numerous subequal to unequal concentric, coarsely linear pliciform growth lines, whose sequence is usually interrupted by remote and more elevated folds,

[a] The cardinal teeth are here regarded as 3 in each valve, but with 1 in each valve obsolete.

imbrications, or constrictions that tend to mark off the surface into regular stages.

Measurements.—The type measurements—height, 72 mm.; length, 83 mm.; breadth, 55 mm.—are those of a rotund-ovate example. The height is often somewhat less in proportion to the length. Adult specimens of average inflation have the breadth equal to about two-thirds of the height. The maximum known size is indicated by an imperfect specimen, which has a height of 79 mm.

Occurrence.—This is one of the commonest and most conspicuous of the fossils of the Malone formation. It ranges through all of the fossiliferous part of the Theta subdivision that is exposed in the Malone hills, occurring not only at the principal collecting ground, a mile and a half east of Malone station, but also west of the Trio. About 90 specimens were collected at the former locality. Examples were obtained from the west side of the north end of Malone Mountain, at the same horizon and locality that yielded the specimens of Nautilus; from the first high ridge west of Malone Mountain, about 2 miles west of Malone station, and from a locality about 1 mile east of Finlay station. A probable example was obtained by Doctor Stanton from the western foothills, 2 miles north of the southern end of Malone Mountain, and a distorted one was found by me on the anticline in the east side of the mountain, about a mile from its southern end.

Rotund-ovate, transverse-ovate, and oblique or rhombic-ovate are all more or less closely approached by the lateral profile of this shell as preserved, which also in some cases is nearly equilateral. A part of this variation, but evidently not all of it, is to be attributed to the dynamical stresses to which the Malone rocks have been subjected. In young examples the form is usually more oblong, less equilateral, and less compressed, and the concentric ribbing becomes more pronounced and regular, approaching the type of ornamentation commonly seen in medium-sized and small species of Astarte.

The species seems to be sufficiently near the Jurassic section, Cœlastarte, of Böhm.[a] It differs from *Astarte excavata* Sby., the best known representative of that section, in being less strongly inequilateral and in having none of the cardinal teeth striated. The central cardinal of the right valve, while it is the largest tooth of the shell, is relatively smaller than that of *A. excavata* as figured by Böhm. In form it approaches the sinupalliate species *Astarte neocomiensis* d'Orb, from which it differs by hinge details and its crenulated margins.

Stoliczka[b] observes:

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[a] Cœlastarte und Heteropis, Ber. Naturf. Ges. Freiburg, i. B. Bd. 7, 1893, pp. 169–178, Pl. VIII.

[b] Cret. Pelecypoda of Southern India, p. 285. Memoirs of the Geological Survey of India. Palæontologia Indica, vol. 3, Calcutta, 1871.

Eriphyla especially seems to be largely represented among the fossil Astarte, as recorded at the present time, and probably all the species which have an indication of a posterior pallial sinus belong to the former genus. They can scarcely be referred to Astarte, for the single anal opening which the animal of this last possesses lies behind the posterior muscular scar, but not below it, where the formation of a sinus, if present, must be due to the development of muscles supporting a branchial siphon, or at least a special branchial opening. Neither of these are, however, present in Astarte.

But so gradual is the transition from none to a well-marked pallial sinus that it seems impossible in practice to distinguish Eriphyla from Astarte clearly by this criterion.

Astarte posticalva sp. n.

Pl. XI, figs. 5, 6.

Shell small, thin, triangular-ovate, of intermediate convexity; beaks rather prominent and pointed, directed somewhat forward, anteriorly excavated, placed near and usually back of the limit of the anterior third; posterior slope a little flattened; anterior three-fourths (to four-fifths) of shell ornamented with numerous linear concentric costellæ, which are separated in strong relief by deep striæ about half as wide as themselves; the flattened posterior fourth or fifth forming a sort of area which is plain, or marked with ordinary growth lines only, and is separated from the preäreal surface by a very obtuse or rounded radial angulation which is not of itself a discrete and salient feature, but consists merely of the rather abruptly curved transition from the outer to the flattened posterior slope of the shell. The costellæ are deflected at their posterior ends, vanishing rather rapidly, but not abruptly, as they approach the plain area.

Measurements.—Height, 13 mm.; length, 15 mm.; breadth, 10 mm. A valve of another specimen has a height of about 14 mm. and a length of 17 mm.

Occurrence.—Not infrequent 1½ miles east of Malone station. Twenty-one specimens were collected.

Astarte? isodontoides sp. n.

Pl. XI, figs. 8, 9.

Shell small, gibbous, inequilateral, oblong-ovate, the dorsal line gently declivous and slightly convex back of the beaks and very feebly excavated in front of them; base nearly straight; anterior side rounded; posterior side obliquely truncated; beaks low, in contact, situated near the anterior third, an obtuse umbonal ridge or inflation extending from their summits to the postero-ventral margin, and the greatest breadth of the shell being, by reason of such infla-

tion, near the anterior limit of the posterior third; flanks and postumbonal slopes more or less flattened; ligament external, short; surface of shell concentrically striate, or ornamented with numerous strong linear elevations whose development varies, and is more regular on the proximal part of the shell, while on the distal part there are one or two excavated zones bounded by high lines. The lines run nearly straight for a considerable part of their course parallel to the base, turning upward more shortly at the posterior than at the anterior end of it.

Measurements.—Height, 13 mm.; length (restored), about 18 mm.; breadth, 10 mm.

Occurrence.—A mile and a half east of Malone station. Only 1 specimen of the typical form was obtained. Of 3 others believed to be only young and compressed examples of the species, 2 are more or less complete right valves, 1 of which shows a ligamental groove and a strongly denticulated inner margin; and the third is a shell quite flattened out. All three of these young examples agree with the proximal and differ from the distal part of the type shell in having a tendency to a rather uniform and close development of the concentric linear costellæ.

The specific name refers to some resemblance which the shell presents in form to that of Isodonta, as represented by the type of tha. genus, *I. deshayesii* Buv.

ASTARTE? CRATICULA sp. n.

Pl. XI, fig. 7.

Shell small, rather ventricose, subovate, strongly depressed along a narrow zone near the posterior cardinal border from the beaks to the posterior extremity; beaks well inflated, moderately elevated, placed somewhat in advance of the middle and back of the anterior third; postero-dorsal flattened area separated from the rest of the shell by a radial angulation and itself divided into two concave zones by a radial cariniform angulation; the general surface of the valves ornamented rather closely with regular, blunt-topped, concentric costellæ, which are in strong relief and separated by intervals of about their own width. The ornamentation of this shell recalls the genus Trigonia.

Measurements.—Estimated measurements only can be given, the margins of both valves of the type being imperfect. The apparent approximate dimensions are: Height, 22 mm.; length, 28 mm.; breadth, 17 mm.

Occurrence.—The only specimen obtained is from the locality 1½ *miles east of* Malone station.

CRASSATELLIDÆ.

Genus PTYCHOMYA Agassiz.

PTYCHOMYA STANTONI sp. n.

Pl. XII, figs. 4–6.

Shell small, compressed, cuneate-ovate or trapezoid-ovate, a little excavated at the front of the beaks; the anterior side short, rounded; the posterior side long; the dorsal margin having a gentle and nearly straight descent back of the beaks for a considerable distance and then declining more rapidly, so that the posterior side of the shell is obliquely truncate above; the base nearly straight in its median and major portion; the posterior umbonal slope forming with the outer slope a gentle shoulder; valves thick, their margins crenulated within: beaks very little salient; lunule cuneate-lanceolate, deeply excavated; surface ornamented with a considerable number of ribs which form an anterior nearly vertical series of upwardly directed chevrons below the beaks, and a posterior oblique series of nearly closed, distally directed angles whose apices lie on the umbonal shoulder; on the posterior part of the shell the ribs pursue a nearly straight course backward and downward to the basal and posterior margins, though arranged in two converging sets, in each of which they are slightly divergent; on the anterior region they are subhorizontal, curved forward and upward, and often minutely undulated or zigzagged. The sides of the subumbonal chevrons, exclusive of the part that forms the usually more or less cuspidate apex, diverge at an angle which is right or sometimes slightly acute in the earlier ribs and becomes quite obtuse in the later ones. The ribs are generally linear-compressed and separated by broader concave intervals, but in occasional specimens, and especially on the posterior region, are more obtuse, with the intervals equaling or distally exceeding them.

Measurements.—A nearly complete right valve indicates: Height, 16.5 mm.; length, 31 mm.; breadth, 8 or 9 mm. An internal cast of a right valve gives: Height, 18 mm.; length, 32 mm.

Occurrence.—Twenty-three specimens, in part only fragments, with the characteristic ornamentation, are in hand. All are from the locality 1½ miles east of Malone station, and most, if not all, from the lower part of the Theta beds there outcropping.

In pattern of ornamentation and in size *Ptychomya stantoni* comes nearest to *Pt. complicata* Tate, from which it differs in having the beaks less anteriorly placed and the posterior truncation very oblique instead of nearly square; the position of the beaks and the line of chevrons below them is as in *Pt. koeneni* Behrendsen. The general form has some resemblance to the latter species, but its lateral profile departs more from a regular oval and tends toward a cuneate.

differs from *Pt. koeneni* also by its much smaller size, and in the absence of small downward-pointing chevrons at the apices of the middle and lower of the large upward-pointing ones.

The species is named after Doctor Stanton, who first recognized its genus on seeing it in my collection at Sierra Blanca, Tex., he having previously ascertained that *Pholadomya ragsdalei* Nobis belongs also to Ptychomya. Doctor Stanton has recently shown me two casts of the latter species on which the hinge characters of the left valve, as described and figured by Pictet and Campiche,[a] are well displayed.

The Ptychomyæ hitherto described, so far as known to me at this time (1899), are as follows:

Ptychomya robinaldina (d'Orbigny), 1843, Pal. Fr., Terr. Cret., vol. 3, p. 75, pl. 264, figs. 10–13.

Ptychomya solita (d'Orbigny), 1851, Rev. et Mag. de Zoöl., 2d series, vol. 3, p. 381, pl. 10, figs. 3, 4.

Ptychomya sp. Unnamed. Described and figured, 1857, by Pictet and Renevier in Pal. Suisse, Terr. Aptien de la Perte du Rhône, et Ste. Croix, p. 90, pl. 11, figs. 2a, 2b, 3a, 3b, as of *Pt. robinaldina* (d'Orb.), but removed from the latter by Pictet and Campiche in 1866 (Pal. Suisse, Foss. Terr. Cret. Ste. Croix, p. 357), and placed near *Pt. neocomiensis* (de Loriol) either as a variety of the latter or a distinct species.

Ptychomya buchiana (Karsten), 1858, Geognost. Verhältn. des Westl. Columb., Bericht 32 ste Versamml. Deutsch. Naturf. u. Ärtze, p. 113, Pl. V, figs. 7a, 7b.

Ptychomya neocomiensis (de Loriol), 1861, Descr. des Anim. Foss. du Mont Salève, p. 71, pl. 9, figs. 1–4.

Ptychomya dædalea Coquand, 1866, Mon. Pal. de l'Étage Aptien de l'Espagne, p. 127, Pl. XX, figs. 1, 2.

Ptychomya germani Pictet and Campiche, 1866, Pal. Suisse, Terr. Cret. de Ste. Croix, p. 354, Pl. CXXVII, figs. 7, 8.

Ptychomya complicata (Tate), 1867, Quart. Jour. Geol. Soc. London, vol. 23, Pt. I, p. 160, Pl. IX, fig. 8.

Ptychomya zitteli Dames, 1873, Zeitschr. Deutsch. Geol. Gesellsch., vol. 25, p 380, Pl. XII, figs. 1, 2.

Ptychomya sp. Unnamed. Described and figured, 1882, by Franz Toula in Denkschr. Kais. Akad. Wissensch. Mat.-Nat. Cl., Bd. XLIV, 2te Abth., p. 35, Pl. IV, fig. 18. Regarded by Toula as probably identical with *Pt. neocomiensis*, though he notes differences. It seems to me to be separated by its strongly arched principal costæ and dorsal border, as well as by its size.

Ptychomya koeneni Behrendsen, 1892, Zeitschr. Deutsch. Geol. Geselsch., vol. 44, p. 23, Pl. II, fig. 4, and pl. 3, figs. 8a, 8b.

Ptychomya ragsdalei (Cragin), 1895, Colorado College Studies, V, p. 58.

In addition to the above, a species of Ptychomya has been reported by G. Steinmann[b] as occurring in the Cordilleras at Chillan, Chile, possibly in the same bed with *Trigonia transitoria* Steinmann. This Trigonia occurs also at Caracoles, Bolivia, from an unknown horizon

[a] Pal. Suisse, Terr. Cret. de Ste. Croix, p. 351, Pl. CXXVII, figs. 9d, 9e.

[b] *Neues Jahrbuch f.* Min., etc., 1882, vol. 1, p. 224.

that, on the ground of the kind of rock attached to the specimen, Professor Steinmann regards as probably Lower Cretaceous, though nearly all of the Mesozoic fossils that he lists from Caracoles he considers Jurassic. I am not aware that the Chillan Ptychomya has been specifically named or described.

The orbicular, toothless, divaricately ornamented shell described by Lycett[a] as *Ptychomya? agassizii*, and the elongate *Pandora? æquivalvis* Deshayes[b] and *Crassatella cornueliana* d'Orb.[c] which have been referred to Ptychomya by some paleontologists, are here, following Stoliczka,[d] excluded from the genus.

The size of the shell in Ptychomya seems to have been less in the earlier history of the genus and to have reached its maximum in the Gault. The relation of size to time is indicated in the following table, in which an attempt has been made to group the species roughly in accordance with their relative geological position, known or supposed:

Table showing sizes of species of Ptychomya at various geological epochs.

Species.	Length.	Geological position.	Locality.
	mm.		
zitteli	90	Turonian	Western Alps.
ragsdalei	105	Upper part of Denison stage	Northern Texas.
buchiana	120	Gault	United States of Colombia.
dædalea	110	Aptian	Spain.
(Unnamed)	80	Aptian	Switzerland.
solita	80	(? Upper part of) Lower Cretaceous	United States of Colombia.
(Unnamed)	67	Uppermost Neocomian (probably fide Toula).	Western Balkans.
neocomiensis	60	Lower and middle Neocomian	France, Switzerland.
koeneni	57	Neocomian[e]	Argentine Cordilleras.
robinaldina	35	Lower and middle Neocomian[f]	France, Switzerland, England.
germani	40	Lower Neocomian (Valangian)	St. Croix, Switzerland.
complicata	31.7	Lower Neocomian? (Jurassic?)	Cape of Good Hope.
stantoni	32	Malone	Southwestern Texas.

[a] Proc. Cotteswold Naturalists' Club, vol. 1, p. 69, Pl. II, figs. 6, 6a.
[b] Mem. Soc. Géol. de France, vol. 5, p. 4, pl. 3, figs. 7a, 7b.
[c] Pal. fr., Terr. Crét., vol. 3, p. 74, pl. 264, figs. 7–9.
[d] See Cret. Fauna Southern India, vol. 3, p. 294.
[e] Behrensden compares his species with the lower and middle Neocomian species, *germani* and *robinaldina*.
[f] Morris and E. Forbes have recorded this species from the lower Greensand; but these records are early ones (1845 and 1854) and not improbably refer to *Pt. neocomiensis*, which was not established till 1861. A species close to *Pt. neocomiensis*, and perhaps not specifically distinct from it, was referred to *robinaldina* by Pictet and Renevier as late as 1857 to 1866. See remarks in above list of hitherto-described Ptychomyæ.

LUCINIDÆ.

Genus LUCINA Brug.

LUCINA POTOSINA C. and A.

Pl. XIII, figs. 4, 5.

Lucina potosina Castillo and Aguilera, 1895, Bol. Com. Geol. Mex., No. 1, p. 6, Pl. IV, figs. 2, 3, and 6; and Pl. V, figs. 11 to 14.

Five specimens from the locality 1½ miles east of Malone station seem to agree sufficiently well in size and form with the small, transverse and rather inflated Sierra de Catorce shells that constitute the type variety of *Lucina potosina*.

The following is a translation of Castillo and Aguilera's description of the species:

Shell transversely oval, relatively compressed, inequilateral. Buccal region longer than the anal, uniformly rounded at its extremity and nearly of the same width as the anal. Lunule well developed, rather deep and generally wider in the right valve. Anal region nearly of the same breadth as the buccal, rounded at its extremity, more inflated than the buccal region. Ligamental area narrow, deep, and elongated, occupying the whole length of the anal region. Cardinal border slightly concave on the buccal side and straight or gently convex on the anal side. Umbones subcentral, contiguous, and a little inclined to the buccal side. Ventral or lower border little curved, joined to the anterior and posterior borders by arcs of more pronounced curve than its general curvature. Flanks convex, more inflated below the beaks where the major convexity is found; this diminishes gradually toward the borders. Surface adorned with delicate concentric costellæ, little salient and separated by plain intervals four to six times wider than the costellæ. Length, 19, 20.5, 21 mm.; breadth, in relation to the length, 0.79, 0.80, 0.85; thickness, in relation to the length, 0.47, 0.48, 0.48.

The exact geological position of *Lucina potosina* at its type locality is not known, as the records are somewhat conflicting. Castillo and Aguilera state, on page 8 of the above-cited bulletin, that the types of this species and of *Cyprina coteroi* were found associated with Alamitos fossils, but were petrified in flint, believed to have been derived from the flint-bearing limestones of their "grupo superior," that overlie the sandstones of the Cieneguita (Lower Cretaceous) as the Cieneguita in turn overlies the Alamitos (Upper Jurassic). On page 49 of the same they omit *Cyprina coteroi*, but include *Lucina potosina* in the list of fossils of the grupo superior, and state that *Schloenbachia af. inflata* is the only fossil found in the limestones of the grupo superior, ascribing *Lucina potosina* and the other fossils of the grupo superior to calcareous and marly shale below the limestone, in the base of the grupo. Finally, on page 50, *Cyprina coteroi* is given as one of the fossils of the Alamitos beds, which are Upper Jurassic. In view of the confusion that has arisen regarding the original stratigraphic source of these fossils, and the further fact that the actual collecting of them seems to have been from among the fossils of the *Alamitos, there* would appear to be some uncertainty as to their

having come from the flint-bearing limestones of the grupo superior, notwithstanding the flinty character of their fossilization and a possibility, at least, that both species may have come from some minor intercalation or segregation of siliceous matter in either the Cieneguita or the Alamitos beds.

LUCINA POTOSINA var. METRICA var n.

Pl. XIII, figs. 6–10.

Lucina metrica Cragin, 1898, Jour. Geol., vol. 5, p. 817.
Lucina potosina ? Cragin, 1898, loc. cit., p. 817 (footnote) and p. 819.

Shell equivalve, compressed or little inflated, flattish-lenticular, suborbicular, yet tending somewhat to a four- or five-sided outline, usually a little transverse, but often not markedly so, sometimes about equilateral, for the most part slightly, and in exceptional cases considerably, inequilateral; valves thin; postero-dorsal region somewhat especially compressed in contrast with the gently inflated umbonal region in front of it, the concavity here being counterbalanced by a feebler compression of the antero-dorsal region; beaks very small and depressed, subcentral, usually placed a little back of the middle; surface ornamented with widely and regularly interspaced, strongly and abruptly elevated, linear-compressed, concentric costellæ. The spaces between the latter are about six times as wide as the costellæ themselves, flat, marked only with numerous and fine crowded, concentric growth lines; and are remarkable for the regularity of their breadth, which increases distally with almost imperceptible increments, but shows occasional variations.

Measurements.—Height, 34 mm.; length, 35 mm.; breadth, 10 mm. in a specimen of the commoner and intermediate size, much smaller specimens being similarly proportioned. For the same dimensions, an example of average adult size and an exceptionally large one give, respectively, 41, 45, 14, and 54, 59, 16 mm.

Occurrence.—A mile and a half east of Malone station. One of the more abundant fossils there occurring, but less common than the *Pleuromya inconstans*. More than 200 specimens are represented. A few examples were also obtained in foothills at the northwest end of Malone Mountain, about 2 miles east-southeast of Finlay station, and west of the mountain, 2 miles north of its southern end.

The height of the shell in *L. potosina*, var. *metrica* is commonly from 90 to 97 per cent of the length, which, however, it may occasionally equal. The breadth averages less than 30 per cent of the length; in 10 measured specimens it averages 29.46, the minimum being 25.5, and the maximum being 32 per cent. The corresponding ratios given by Castillo and Aguilera for typical *potosina* are height as percentage of length 0.79 to 0.85, and breadth as percentage of length 0.47 to 0.48.

From all of the data above given it is seen that the shell of var. *metrica* attains a much larger size than that of var. *potosina*, is considerably less inflated, and has a less transverse (i. e., more elevated) and more nearly equilateral contour.

Lucina potosina, var. *metrica* is not only a pronounced variety of its species but it is the largely preponderating representative both of its species and of its genus in the Upper Jurassic of western Texas.

As is usually found to be the case where very large numbers of a species of fossil are available for study, *L. potosina* presents considerable individual variation. Seven or eight specimens from locality 1½ miles east of Malone, represent a third variety of the species, which is apparently only an individual phase, though rather a striking one, of var. *metrica*. They show the following characters: The shell is about as large as the largest examples of the ordinary form of *metrica;* transversely broad-oval, inclining to subquadrate; inequilateral; inflated throughout, though unequally so, the valves being radially warped or flexuous, and especially swollen on the umbonal slope, on either side of which are two broad and shallow concave radial zones, the anterior one of which passes downward and the posterior one downward and backward; a second and smaller convex radial zone being developed in front of the anterior concave one. The beaks are more inflated than those of the typical form of var. *metrica*. The basal margin of the shell is a little prominent and receding opposite the convex and concave zones, respectively. Corresponding with the general contour of the shell, the concentric linear costellæ, which in the common phase of var. *metrica*, have an almost uniform downward convexity in the postero-basal part of their course, assume in this phase a nearly straight or slightly upward convex trend for a considerable distance in this part of their course, swinging upward rather suddenly anterior and posterior to it. The approximate dimensions are: Height, 45 mm.; length, 50 mm.; breadth, 20 mm.

This phase, then, is distinguished from the ordinary phase of var. *metrica* by its size, average adult examples of the latter being considerably smaller, by its greater and more pervasive inflation, strongly flexuous valves, and more transverse and inequilateral contour. A tendency toward this form is seen in some of the smaller examples of the other phase of *metrica*.

LUCINA ? EMARGINATA sp. n.

Pl. XIII, figs 1, 2.

Cf. *Cyprimeria ? mexicana* Castillo and Aguilera, 1895, Bol. Com. Geol. Mex., No. 1, p. 9, Pl. V, fig. 3.

Shell suborbicular, compressed, though less so than that of *Lucina potosina, var. metrica*, the breadth being equal to about half of the

height; anterior, ventral, and posterior sides rounded; dorsal side abruptly and emarginately excavated before the beaks to a point distant one-fourth of the shell length, where it joins the anterior side in an obtuse angle, the posterior part of the dorsal side declining in a nearly straight line, with some convexity near the beaks, to a point two and a half times as remote, where it makes an obtuse angle with the posterior border; beaks low, with apex curved forward; lunule large, about twice as long as wide, abruptly and rather deeply impressed; margins entire; surface ornamented with rather coarse, rounded, subdued, concentric costellæ separated by equal or narrower intervals, each costella making an irregular and gentle undulatory flexure as it approaches the posterior part of the dorsal margin.

Measurements.—In an accidentally somewhat compressed specimen, height, 21 mm.; length, 22 mm.; breadth, 7 mm. In a second example, height, 20 mm.; length, 19 mm.; breadth, 10 mm. In a third, height, 32 mm.; length, 30.5 mm.; breadth about 16 mm.

Occurrence.—Three examples were obtained from the locality 1½ miles east of Malone station.

In the absence of a satisfactory knowledge of the hinge details, the species is here placed in the genus *Lucina* because of the abruptly excavated and rather deep lunule, the lunule in *Cyprimeria* being feebly excavated or lacking.

LUCINA PLANIUSCULA sp. n.

Pl. XIII, fig. 3.

Shell of intermediate size for *Lucina*, thick-valved, broadly suboval, rather inflated, the breadth equal to more than half of the height, height equaling about five-sixths of the length, moderately inequilateral, the posterior side being between three-fourths and four-fifths as long as the anterior, the latter but little contracted; beaks little prominent; surface nearly plain, ornamented with inconspicuous, concentric raised lines and striæ, which on the major part of the surface are more or less obsolete, but are more distinct on the anterior and posterior marginal regions, the raised lines on the latter being very fine and intervaled on the upper part, becoming coarser and more crowded below.

Measurements.—Height, 26.5 mm.; length, 31 mm.; breadth, 15 mm.; in another example, height, 28 mm.; length, 31 mm.

Occurrence.—Four shells and about a dozen casts of this fossil were collected in foothills in the northwest end of Malone Mountain, about 2 miles east-southeast of Finlay station.

From *Lucina coetoi* C. and A., the *L. planiuscula* appears to differ chiefly by its more strongly inflated and much less strongly inequilateral shell and its plainer ornamentation.

Genus UNICARDIUM d'Orbigny.

UNICARDIUM ? SEMIROTUNDUM sp. n.

Pl. XII, figs. 9–11.

Shell thin, pyramido-suborbicular, moderately inequilateral, well inflated, the height nearly equal to the length; beaks large and prominent, pyramidal, submedian, placed a little nearer to the anterior than to the posterior extremity, curved inward and slightly forward, so that the anterior cardinal border is more concave than the posterior; anterior and posterior borders rather short; base evenly and rather broadly rounded; surface marked only with fine concentric growth lines, most of which are rather feebly, a few more strongly, impressed.

Measurements.—Height, 21 mm.; length, 22 mm.; breadth, 13 mm. Height in another nearly like-proportioned example about 25 mm.

Occurrence.—Twelve specimens were collected by Doctor Stanton at the following four localities: A mile and a half east of Malone station; anticline in east base of Malone Mountain about 1 mile north of its southern end; west of Malone Mountain, nearly 2 miles south of west from Malone station, in No. 13 of his Malone Mountain section; and in foothills at the northwestern end of Malone Mountain, a little over 2 miles east-southeast of Finlay station, here also apparently in No. 13. Four examples were also collected by me at the first of the localities above named.

The species shows some resemblance in form to *U. varicosum* Sowerby, but has larger and more elevated umbones and, for the body of the valves, a more rotund contour.

UNICARDIUM ? TRANSVERSUM sp. n.

Pl. XII, figs. 7, 8.

Shell thin, well inflated, transversely subovate, the height equaling 0.77 to 0.87 of the length; the posterior moiety of the shell narrower and considerably longer than the anterior, and the anterior part of the cardinal border more concave than the posterior; base broadly and unequally rounded; beaks prominent, yet less so than those of *Unicardium semirotundum*, in contact; surface smooth, marked only with fine concentric growth lines, which disappear under slight weathering. While the form of the shell is persistently transverse or subovate, the position of the beaks is widely variable, as shown by the umbonal fractions below, in which the numerator and denominator, respectively, denote the distances in millimeters of the umbonal summits from the anterior and posterior ends of the shell *in four specimens* selected at random. That this variability, how-

ever, is in part due to the orogenic movements which the matrix has undergone is indicated both by other variation in the form and by the discrepancy sometimes shown in the relative position of the two beaks of a single shell.

Measurements.—Height, 26 mm.; length, 34 mm.; breadth, 21 mm. Same dimensions from a left valve, respectively; height, 24 mm.; length, 29.5 mm.; breadth (by doubling the convexity of one valve), 15 mm. Umbonal fractions, $\frac{1}{3}$, $\frac{5}{12}$, $\frac{1}{4}$, $\frac{1}{3}$.

Occurrence.—Fourteen specimens were collected from the locality 1½ miles east of Malone station; one from the anticline on the eastern slope of Malone Mountain nearly 1 mile north of the southern end; and one also upward of 1 mile east of Finlay station.

CYPRINIDÆ.

Genus CYPRINA Lamarck.

CYPRINA COTEROI C. and A.

Pl. XIII, figs. 11, 12.

Cyprina (*Venilia*) *coteroi* Castillo and Aguilera, 1895, Bol. Com. Geol. Mex., No. 1, p. 8, Pl. V, figs. 4 to 10.

Shell thin, triangular-ovate, inequilateral, ventricose, the height generally equaling one and a third to nearly one and a half times the breadth and about seven-eighths of the length; posterior slope flattened and separated from the rest of the shell by a low crest, or angulation, which runs from the posterior side of the beaks to the somewhat pointed infero-posterior end of the shell; beaks situated between the middle and the anterior third, strongly inflated, high arched, pyramidal, incurved, somewhat anteriorly deflected, and nearly, if not quite, in contact; pallial line entire; general surface ornamented with ordinary concentric growth lines and at remote intervals with resting stages marked by moderate imbrication and groove, which descend across the posterior flattened area and turn suddenly forward at the posterior angulation.

Measurements.—Height, 34 mm.; length, 41 mm.; breadth, 27 mm.

Occurrence.—Four (and two doubtful) specimens, from locality 1½ miles east of Malone station.

There is some doubt as to the true horizon of the type specimens of this fossil. See remarks as to same on page 72, under *Lucina potosina*.

CYPRINA? STREERUVITZII Cragin.

Pl. XIV, figs. 1, 2; Pl. XV, fig. 1.

Cyprina (Roudairia?) streeruvitzii Cragin, 1893, Fourth Ann. Rept. Geol. Survey Texas, pt. 2, p. 180, Pl. XXXVI, figs. 3 to 5, and Pl. XL, fig 2.

Cyprina streeruvitzii has been found only in the Theta, and can hardly be called an abundant fossil. Notwithstanding its large size and the fact that special search was made for it at its type locality, 1½ miles east of Malone station, the most prolific lamellibranch field known in the Malone formation, only 11 incomplete specimens and casts were found, and none of these is as good as the specimen collected there by Mr. Wyschetzki, the topographer of Mr. Von Streeruwitz's party, in 1890. They were all, or nearly all, obtained from the west slope of the Truncate mound.

They add little to our knowledge of the species.

The cast, owing to its narrow, very elevated, and strongly arched beaks, bears considerable resemblance to that of *Cyprina texana* Conrad. Its posterior area is outwardly bounded by an obtusely compressed, prominent ridge, interior to which is a round-bottomed sulcus, followed by another radial elevation and depression within. The casts of the anterior adductor scar are exceedingly prominent. An undersized though apparently normally proportioned cast has the height 73 mm.; breadth, 64 mm., and length approximately 80 mm. The largest example of the shell has the beaks broken off, but has a length of about 124 mm. Another specimen of the shell presents a height of about 106 mm.

Attached to some of the specimens by the stony matrix are characteristic parts of *Trigonia vyschetzkii*, *T. proscabra*, *Lima interlineata*, *Astarte breviacola*, *Mytilus nuntius*, *Serpula gordialis*, and other fossils.

There remains some doubt as to the genus of this shell, as the hinge characters have not been observed. The following is the original description of the species:

Shell large, triangular, the anterior and posterior sides of the outline being subdirect, the basal convex, height and length of shell about equal, exceeding the breadth; beaks prominent, situated somewhat in advance of the middle, posteriorly flattened or concave, their summits turned inward and forward till tangent or subtangent above the downward, outward, and backward curled apices, the latter overhanging a large and deeply impressed heart-shaped lunule, which is higher than wide, and is bounded by a moderate slope, the margins of the valves immediately below the lunule forming no such keel as is seen in *Cyprina roemeri*, the anterior termination of the shell being, on the contrary, very obtuse; posterior slope in either valve bicarinate, having, in addition to the primary angulation which abruptly separates the discal from the *posterior slope, a* second and similar radial angulation at a position which is at

first about two-thirds of the distance from the primary angulation to the posterior shell-margin, and which at length reaches that margin at rather more than two-thirds of the distance from the beaks to the distal extremity of the primary angulation; intercarinal areæ concave, that included by the secondary carinæ forming an escutcheon, those included between the primary and the secondary carinæ continuous with the posterior flattening of the umbonal summits; entire exterior of the shell presenting numerous strong concentric growth lines and divided off on the disk into rather broad, subequal, concentric zones by narrow, low, and, in part, obsolescent concentric ribs. Valves thick.

Measurements.—Height, 88 mm.; length (approximately), 93 mm.; breadth, 74 mm.

VENERIDÆ.

Genus TAPES Megerle.

TAPES? CUNEOVATUS sp. n.

Pl. XIII, fig. 13.

Shell gently compressed, thin, cuneate-ovate; the convex-tapered posterior side narrowly rounded at the end; anterior side rounded; base gently convex; dorsal margin rather abruptly excavated at front of beaks; breadth contained about one and a half times in height; height about one and a half in length; beaks placed at posterior limit of anterior third; surface finely concentric striate.

Measurements.—Height, 17 mm.; length, 24.5 mm.; breadth, 10 or 12 mm.

Occurrence.—A mile and a half east of Malone station; represented by a right valve complete as to form, but with the larger part of the shell removed by weathering, enough, however, remaining to show the character of the ornamentation.

PHOLADOMYIDÆ.

Genus PHOLADOMYA Sowerby.

PHOLADOMYA TOSTA (Cragin).

Pl. XV, figs. 2, 3.

Anatina tosta Cragin, 1893, Fourth Ann. Rept. Geol Survey Texas, pt. 2, p. 168.

Pholadomya tosta Cragin, 1897, Jour. Geol., vol. 5, p. 817.

Shell large among its congeners, moderately ventricose, very inequilateral, oblong, with rounded extremities and long, straight-convex to feebly sigmoid base, pointed-ovate in cross section; the anterior region short; the posterior region long and somewhat narrowed, its cardinal margin feebly concave; beaks low-arched, in contact, placed at about a fifth (sometimes less) of the shell length from the anterior end; entire shell presenting fine growth lines and irregularly intervaled, coarser, concentric imbrications, which on an anterior small

and a supero-posterior larger area constitute the only markings, all of the shell except these terminal areas being crossed by radiating ribs, of which there are about 20 on either valve. The ribs are narrowly compressed and rather strongly elevated (cariniform), often with irregularly crinkled summits, and some of them are pressed backward so that the posterior slope is comparatively gentle, while the anterior is steep or overhangs, giving them somewhat the appearance of imbrications; they are unequally remote and separated by broad, flattish-concave intervals; and one of the posterior ribs is usually higher and larger than the others, the two or three that are yet posterior to this, and a few of the anterior ribs, being less pronounced than the others. The anterior part of the base is gently convex, becoming straighter and gradually a little rising posterior to a point between the middle and the posterior end, and again apparently a little descending or prominent opposite the largest one of the posterior ribs, the base describing thus a feebly sigmoid curvature. The latter feature is not seen in all specimens, and may be due to mechanical distortion.

Measurements.—The two largest specimens average about 50 mm. in height. The breadth is apparently about three-fourths of the height, and the height about half of the length.

Occurrence.—Twenty-five specimens are represented from locality 1½ miles east of Malone station.

PHOLADOMYA MARCOUI sp. n.

Pl. XVI, figs. 1, 2.

Shell of medium or small-medium size in its genus, very inequilateral, short-oblong or ovate-oblong, more or less rounded at both extremities, ventricose; posterior cardinal border slightly excavated; the posterior region convex-cuneately compressed, gaping narrowly at the upper posterior border; beaks situated near the anterior end, elevated about as in *Pholadomya candida* Sby., or *P. glabra* Ag.;[a] surface, except small anterior and posterior dorsal portions, ornamented with a few (about 6?) remote, feebly expressed, or obsolescent, cariniform, radial ribs, the posterior one of which is directed nearly straight backward (slightly downward), and also unevenly marked with coarse concentric growth lines.

Measurements.—Height, 36 mm.; length, 56 mm.; breadth, 32 mm.

Occurrence.—A mile and a half east of Malone station. This Pholadomya seems to be less common than either *P. tosta* or *P. dumbli*. Ten examples were obtained.

This or a closely related form was found with *Exogyra potosina*,

[a] Referring here to the species as presented in pls. 108 and 109 of Tryon's Structural and Systematic Conchology.

etc., at the western base of Malone Mountain, a short distance north of its southern end, the cast bearing indications of feeble ribs about as in *marcoui*, but this form—perhaps modified by orogenic movements of the matrix—being longer, lower, and smaller-calibered than it is normally in the latter species.

The species is named for the late Mr. Jules Marcou.

PHOLADOMYA PAUCICOSTA Roemer?

Pl. XVI, figs. 5, 6.

Pholadomya paucicosta F. A. Roemer, 1836. Verstelnerungen des Norddeutschen Oölithgebirges, p. 131, Pl. XVI, fig. 1.

Form stout, curved-cuneate-pyriform; the umbonal region widely inflated transversely to the length of the shell; anterior region shortened almost back to the large, prominently elevated, tangent umbones, which are thus made almost terminal; the anterior margin slightly gaping; posterior region widened in the median plane, compressed, most strongly so in the upper part, which tends to a keel-like form and gapes considerably; base drawn upward rapidly in the anterior part, so that, in connection with the very salient beaks, the whole anterior (including umbonal) moiety of the shell has an upturned appearance; surface ornamented with coarse, unequal, concentric, costelliform growth plications and furrows and apparently with 4 or 5 low folds radiating from the beaks forward and downward to the basal margin.

Measurements.—The dimensions can be given only roughly. They appear to average, for the larger specimens: Height, 52 mm.; length, 61 mm.; breadth, 48 mm.

Occurrence.—Not rare in the Malone Hills, a mile and a half east of Malone station. Among 26 specimens there collected the mechanical distortion has been such that no two are quite alike. There is, however, a central phase about which they are grouped and to which several of them closely approximate, affording a sufficiently correct idea of the normal form; and so different is the shell from any other found in these beds that it can be recognized in any of its false shapes, though the radial markings are rarely well preserved and often not shown at all. A specimen was obtained by Doctor Stanton near the railroad, about 2 miles east-southeast from Finlay station, in the northwestern foothills of Malone Mountain.

Accepting for the European Upper Jurassic *Pholadomya paucicosta* Roemer, the wide range of specific variation indicated for it by Moesch,[a] it seems impossible to separate the above-described Malone species from it.

[a] Monographie der Pholadomyen. In Abhandl. Schweiz. pal. Gesell., vols. 1 and 2.

PHOLADOMYA PRÆPOSITA sp. n.

Pl. XVI, figs. 3, 4.

Shell small for its genus, cuneate-oblong, arched somewhat downward, very broad across the antero-dorsal or umbonal region, the breadth at least equal to the height, convex-cuneately narrowed toward the base and rear; anterior side rather truncate; base gently convex; beaks anterior, terminal, projecting forward a little beyond the rest of the shell, directed forward and upward, then arched strongly inward, the apices curved a little backward, somewhat compressed as if by gentle pressure on the anterior (or inferior) and posterior (superior) sides; surface with faint concentric markings and several remote, low, slender, cariniform costellæ which radiate from the summit of the beaks, the anterior 6 (or more) obliquely crossing the inferior (anterior) umbonal slope to the base. The anterior part of the base is sharply and even a little biconcavely compressed, and a limited anterior region of the shell is free from the cariniform rays.

Measurements.—Height, 22 mm.; breadth, 22.5 mm. In a second specimen, height, 20 mm.; breadth, 20 mm. The length of these specimens (at least more than 31 mm.) can not be exactly given, as they are posteriorly broken off. A third, with only remnants of the shell, but nearly normal as to shape, gives, height, 20 mm.; breadth, 20 mm.; length, 34 mm. A fourth example, too much weathered on the flanks to give the breadth, has a height of 24 mm., and a length of 43 mm.

Occurrence.—Four examples from locality 1½ miles east of Malone station.

Genus PLEUROMYA Agassiz.

PLEUROMYA INCONSTANS C. and A.

Pl. XVII, figs. 1–5; Pl. XVIII, figs. 1–3.

Pleuromya inconstans Castillo and Aguilera, 1895, Bol. Com. Geol. Mex., No. 1, p. 10, Pl. V, figs. 15, 16, and Pl. VI, figs. 1 to 4.

Pleuromya inconstans Cragin, 1897, Jour. Geol., vol. 5, p. 817, footnote, and p. 819.

Though outnumbered at many points by its associates, this is the most generally distributed fossil of the Malone formation. It ranges through the entire Theta subdivision of the Malone hills (Trio) section, or so much of it as is exposed at the locality 1½ miles east of Malone station, whence several hundred specimens were obtained. It was also collected by me in the lower part of limestones overlying conglomerate in the anticline at the eastern base of Malone Mountain, about 1 mile from the southern end, and was, I believe, found in *poorly* preserved examples in the gap west of the Trio, with *Trigonia*

ryschetzkii and *Astarte malonensis*. The material collected by Doctor Stanton includes part of that from the first two of these and also specimens from the following localities: Two miles west and also about the same distance south of west of Malone station (here in Nos. 13 and 25 of his Malone Mountain section); foothill west of Malone Mountain, 2 miles north of its southern end; and west base of the mountain, near its southern end.

On the anterior part of the umbonal region of this shell there descends to the base a zone of constriction, as if the shell, when plastic, had been pinched, making the valves there gently concave and the base a little reëntrant, a feature which is often pronounced, though sometimes scarcely perceptible. When viewed from below, the base is usually seen to be twisted, presenting a more or less decided right-and-left sigmoid flexure. The right hinge margin overlaps the left. The shell gapes narrowly at the posterior end.

This fossil well sustains the reputation of the Pleuromyas for variability, meriting its specific name even better, if possible, in Texas than in Mexico. Manifold shades of form present themselves—some natural, others dynamical modifications of these—but all seem to intergraduate, and the specific place of many of them becomes indeterminable the moment an attempt is made to group them in more than one species. For this reason and because some of the specimens agree perfectly with those described and figured by Castillo and Aguilera from the Upper Jurassic of San Luis Potosi as *Pleuromya inconstans*, all are referred to that species.

The cuneate, the subcylindrical, and the Gresslya-like variations that have been recorded from the Sierra de Catorce, all are represented in the collections from the Malone district also. What appears to be the central phase for the latter district may be described as follows: The posterior terminal region of the shell is usually somewhat narrowed, sometimes strongly so, and is recurved or obliquely upturned; the anterior margin descends in a convex oblique line to an obtusely pointed or narrowly rounded corner in which it meets the horizontal or often somewhat downward-deflected anterior prolongation of the base. The anterior end thus presents a "Roman-nosed," or "hook-nosed," appearance, and the shell as a whole, viewed laterally, presents a sigmoid flexure, while the basal margin presents such flexure whether viewed from the side or from below. This is by far the most abundantly represented form of the species in the Malone district, and it attains the largest size. That it also occurs in the Sierra de Catorce is indicated by Castillo and Aguilera's very excellent and comprehensive description of the species, of which a translation is here added:

Shell inequilateral, of variable form, sometimes truncate on the anterior border, sometimes with this same border salient; the general dominant form is ovate

trigonal. Buccal region little developed, extremely small compared with the anal region; excavated below the beaks, with its extremity rounded in some individuals, in others obliquely truncated, and salient in its lower part, which is continuous with the ventral border forming an obtuse angle. Beaks situated in the anterior third of the shell, varying their position in the different individuals from nearly terminal to subcentral; broad, convex, sometimes presenting two obtuse keels, one on each side of the apex of the beak. Anal region very large, convex, or depressed, narrowed toward its extremity, which is rounded. Dorsal border straight or slightly concave on the anal side, considerably excavated on the buccal side. Ventral border nearly straight, feebly raised at the extremities, but notably more at the anal side. Flanks sometimes very convex, giving to the shell a cylindrical form, and sometimes depressed so that they make it cuneiform; the greater convexity is always in the anterior part of the shell and below the beaks. Surface ornamented with concentric furrows which contrast with the fine lines of growth. Length, 34 to 63 mm.; breadth with relation to the length, 0.47 to 0.64; thickness with relation to the length, 0.31 to 0.43.

Castillo and Aguilera supplement this description with the following remarks:

We possess of this species only molds and imperfect examples, but these show the ornamentation of the shell and its very feeble thickness. The variation in the characters of this species is not limited merely to the contour and the other details of form of the shell, but is also manifested in the mode of occurrence of the shell, which is equivalve in the more convex forms and evidently becomes more and more inequivalve in so far as it reaches forms in which the right valve is more elevated than the left in such a manner that the dorsal border before and behind the beaks passes over the dorsal border of the opposite valve, exactly as in the Gresslyas, to which genus these forms could be referred without hesitation if they were found isolated, as to some extent the umbonal crests of which we have spoken above would make this position of the shell in the genus Gresslya more proper, since the obtuse furrow which is found along the umbonal crests somewhat resembles the oblique furrow which the molds of the Gresslyas present in the right valve and which in these corresponds to the internal lamina. Fortunately we have met with abundant examples which have permitted us to follow all the variations of the shell, forming a series whose extremes, taken without the intermediate forms, could without hesitation be referred to the genera Pleuromya and Gresslya, respectively.

PLEUROMYA INCONSTANS var. CURTA var. n.

Pl. XVIII, fig. 4; Pl. XIX, figs. 1, 2.

Cuneate-oblong to cuneate-ovate, much shorter than the lengths of *Pleuromya inconstans* that prevail in the Theta member of the Malone formation, and rather compressed; the narrowly gaping posterior region of the shell slightly recurved, obliquely truncate; anterior region closed; ventral margin gently and evenly convex: dorsal margin much less excavated before the beaks than that of *Pleuromya peregrina* d'Orbigny; beaks more nearly terminal than in that species, *often unequally* elevated, the right being the higher, as seen in some

species of Pleuromya and more commonly in Gresslya, the casts, however, lacking the pronounced right dorsal groove of the latter genus.

Occurrence.—In the horizon of *Exogyra potosina*, *Gervillia cinderella*, etc., at the west base of the southern part of Malone Mountain, and in the Theta member of the Malone Hills, 1½ miles east of Malone station. The types are from the former locality. At both places the type variety of *Pleuromya inconstans* as figured by Castillo and Aguilera also occurs, but in the former situation *curta* is common, while in the latter it is rare.

This form, so far as is indicated by the known material from the Malone Mountain locality, does not intergraduate with *Pleuromya inconstans*, and may represent a distinct species; but at the locality in the Malone Hills some of the forms of the multivariant *inconstans* seem to lead up to it, and it is therefore here considered a variety of that species. Its general proportions are not unlike those of the Callovian species *Pleuromya peregrina* d'Orb., from which it is distinguished by the recurved posterior region, the position of the beaks, and the less decidedly excavated anterior dorsal margin.

A Gresslya-like specimen of Pleuromya from the locality east of Malone station, whose form resembles somewhat that of *G. gregaria* Goldfuss, is provisionally considered as a mechanical deformation of this variety, though it may be such of one of the shorter examples of the variety *inconstans*, or even be specifically distinct.

ANATINIDÆ.

Genus ANATINA Lamarck.

ANATINA OBLIQUIPLICATA sp. n.

Pl. XVI, figs. 7, 8.

Shell among the smaller species of its genus, relatively compressed, inequilaterally elongate-oblong, rounded anteriorly, attenuated back of the beaks; the gaping posterior side shorter than the large and closed anterior; the shell somewhat pinched or concave on the ventral part in advance of the beaks (the ventral margin a little tortuous?); beaks small, low, situated near the limit of the anterior third; surface of the thin valves ornamented with concentric growth lines, and on the anterior region with a series of coarse and prominent, oblique undulatory folds which are nearly straight and trend about equally upward and forward. The folds are obtuse at summit and are separated by subequivalent round-bottomed intervals; the distal 5 occupy the valve to a distance of about 14 mm. from its antero-ventral margin.

Measurements.—Height, 23 mm.; length, 53 mm.; breadth, 14 mm. Beaks placed at 30 mm. from the anterior extremity.

Occurrence.—Eight specimens from locality 1½ miles east of Malone station.

ANATINA? PLICULIFERA sp. n.

Pl. XVI, figs. 9, 10.

Shell of small medium size in the genus, oblong, anteriorly rounded, posteriorly truncate, strongly compressed, moderately gaping at anterior and posterior extremities; the posterior region relatively little contracted; beaks low, narrowly compressed with the shell itself, situated about at the posterior limit of the anterior third of the shell; surface ornamented with strong, subequal, concentric plicules and grooves.

Measurements.—Height, 29 mm.; length, 49 mm.; breadth, 14 mm.

Occurrence.—A mile and a half east of Malone station. Represented by only one specimen.

There is some appearance of an anterior radial angulation of the shell, directed forward and downward to the anterior extremity; but the condition of preservation of the type is such as makes it impossible to determine whether this is really a feature of the shell or not.

Genus THRACIA Leach.

THRACIA? MALONIANA sp. n.

Pl. XIX, fig. 6.

Shell very thin, inequilateral, compressed, commonly about the size of *Thracia incerta* Agassiz,[a] sometimes larger, inclined to be more posteriorly produced, or heel-like, at the lower anterior border, trapezoid-ovate; posterior side narrowly gaping in the upper part; beaks of moderate size and elevation, situated about as in the *T. incerta*, their posterior slope angulated; surface marked with parallel, moderately elevated, compressed linear, or cariniform, concentric plicules separated by partly equal and partly unequal intervals of two or three times their own width.

Measurements.—Of considerably the largest example, height, 42 mm.; length, about 60 mm.; breadth, about 20 mm. Of a more common size, height, 37 mm.; length, 49 mm.; breadth, 18 mm.

Occurrence.—Six specimens, all casts, two of which show characteristic traces of the markings, were collected 1½ miles east of Malone station.

[a] As figured in Zittel's Handbuch, vol. 3, fig. 186.

MYIDÆ.

Genus CORBULA Bruguière.

CORBULA ? MALONIANA sp. n.

Pl. XIX, fig. 7.

This name is provisionally proposed for a small, transverse, triangular-ovate, moderately ventricose cast of a right valve belonging apparently to this genus, but unknown as to hinge or shell, obtained by Doctor Stanton from the same horizon that yielded the broadly triangular examples of *Exogyra potosina*, at the west base of Malone Mountain, a short distance north of its southern end. The height is about six-tenths of the length; the posterior end is slightly produced or pointed; the beak is pyramidal; the pallial line is coarse and strongly impressed. The species should possibly be referred to Neæra.

Measurements.—Height, 5 mm.; length, a little more than 8 mm.; breadth indicated for cast (that of the left valve being restored), about 4 mm.

PHOLADIDÆ.

Genus MARTESIA Leach.

MARTESIA MALONIANA sp. n.

Pl. XIX, figs. 3–5.

The types of this species are two casts of compressed-conoidal shape, with portions of the shell, in matrix. They are straight (not at all arcuate) and taper rapidly from the large anterior region. The compression is scarcely expressed in the umbonal region, but increases posteriorly. The base is rectilinear. Radiating downward from either beak to the base are two remote, transversely striated furrows, of which the anterior is the wider and the posterior is the more deeply impressed.

The markings seen on the casts are apparently an index of those peculiar to the shell. The casts do not indicate the character of the accessory plates.

Measurements.—The casts measure, height, 11 mm.; breadth, 10 to nearly 11 mm.; length, upward of 15 mm.; the posterior extremity of each being broken off.

Occurrence.—Obtained by Doctor Stanton in No. 13 of his Malone Mountain section, on the west side of Malone Mountain, south of west from Malone station. Besides the types, a considerable number of less satisfactorily preserved casts and fragments of casts were collected in their borings in fossil wood, at the same locality.

A cast of Martesia referred to this species, obtained at the anticline in the east side of Malone Mountain about 1 mile north of its southern end, shows a more posteriorly produced form than might be inferred from the above-described types, indicating that a considerable length has been broken off from each of the latter.

Borings presumed to have been those of Martesia were also found 1½ miles east of Malone station.

GASTROPODA.

PLEUROTOMARIIDÆ.

Genus PLEUROTOMARIA Defrance.

PLEUROTOMARIA CIRCUMTRUNCA sp. n.

Pl. XIX, figs. 8, 9.

Shell conical, consisting of 5 to 6 flattened or in part concave whorls, the slope of spire nearly straight, that of the entire shell, however, concave, owing to the form of the body whorl; spire acute; sutures lightly impressed, bordered by a low elevation above and below; body whorl concave above the peripheral zone, its periphery canaliculate-truncate, or having two low, abrupt angulations with a narrow, shallow-concave belt between them (and which, in the poorly preserved and sometimes more or less distorted specimens commonly found at the type locality, occasionally appears like a merely flat truncation); surface of the entire shell ornamented with fine, crowded, revolving raised lines, so minute as to be scarcely visible to the naked eye, and of which (in one of the types) there are 11 on the peripheral canal of the body whorl. The aspect of the peripheral canalicular truncation is outward and slightly downward.

Measurements.—Height, 20 mm.; breadth, 19 mm.; angular divergence of the slopes (excluding the body whorl), 66°.

Occurrence.—One and a half miles east of Malone station, in the lower part of the Theta subdivision of the section there exposed; with *Delphinula stantoni*, *Turbo? beneclathratus*, *Natica williamsi*, *Nerita nodilirata*, *Gervillia corrugata*, etc. Represented by eleven examples.

TROCHIDÆ.

Genus TURBO Linnæus.

TURBO ? BENECLATHRATUS sp. n.

Pl. XIX, figs. 10, 11.

Shell rather small, turbinate-conical, composed of about 4 ventricose whorls; spire and body whorl about equal in height; body whorl

flattened and angulated on its upper part, the flattened zone being rather narrow and adjacent to the suture; aperture subovate; outer lip thin (?); inner lip covered with a calcareous callus, which is so arched as to indicate the presence of a low fold or tooth-like protuberance below; entire surface ornamented with a regular, open lattice-work of narrow, strongly elevated, transverse ribs, which are crossed by similar but somewhat more delicate revolving ones, the points of intersection being slightly protuberant to subtubercular, and the rectangular included intervals being gently concave and each marked by several raised growth lines.

Measurements.—Height, 19.5 mm.; breadth, 17 mm.

Occurrence.—A mile and a half east of Malone station; with *Gryphæa mexicana*, *Pleurotomaria circumtrunca*, *Natica williamsi*, etc. Known only by a single specimen, which has the base and the margin of the outer lip broken off. It is possible that specimens with the apertural characters well preserved might show this shell to belong to Purpurina.

Genus DELPHINULA Lamarck.

DELPHINULA STANTONI sp. n.

Pl. XIX, figs. 12–14.

Shell rather small, conoidal-turbinate, narrowly umbilicate, consisting of 4½ ventricose whorls, thick, especially in the vicinity of the peristome; spire about equal to the body whorl in height; aperture circular or nearly so; whorls rather closely ornamented with revolving lines of crowded and small but prominent granules, each granule shown, when the ornamentation is well preserved, to consist of a stout hood-like imbrication; body whorl flattened above in a rather broad zone that looks upward and outward, and is externally limited by an angulation that is marked by a line of relatively coarse and prominent hood-like imbrications, below which, in a narrow zone, the surface of the whorl is again somewhat flattened and looks outwardly, a second line of relatively coarse and prominent granules traversing the flattened upper slope of the body whorl, just below the suture. Between the upper and lower lines of coarse imbrications there are two lines of the smaller ones, and between the lower and the umbilical border there are nine.

Measurements.—Height, 16 mm.; breadth, 13 or 14 mm.; angular divergence of slopes, 80°.

Occurrence.—A mile and a half east of Malone station, in the lower exposed part of the Theta; associated with *Natica williamsi*, *Pleurotomaria circumtrunca*, *Gervillia corrugata*, *Gryphæa mexicana*, and many other, especially of the smaller of the Malone fossils. Five

specimens were collected, four of them by Doctor Stanton, after whom the species is named.

NERITIDÆ.

Genus NERITA Linnæus.

NERITA NODILIRATA sp. n.

Pl. XX, figs. 1–4.

Shell thick, composed of 2½ to 3 whorls, its very obtuse-apexed interior cast loosely coiled and making only about a revolution and a half; body whorl obtusely angulated above the middle, somewhat concave above the angulation and again convex above the concave zone; spire very small, rising but little above the body whorl; aperture semilunar; peristome considerably thickened below; columellar area broadly flattened and overspread with a callus; whorls transversely trenchant-striate, or marked with close and abruptly elevated transverse lines, and bearing tubercular or noded ribs; exposed parts of the spire whorls and the corresponding (upper) part of the body whorl bearing rather remote, compressed, transverse ribs, each of which bears 2 remote nodes (the lower node being at the locus of angulation in the body whorl and just above the inferior suture in spire whorls), these ribs continued as simple ridges across the lower part of the whorls in very young shells, but on the body whorl of older ones giving place to 4 or 5 revolving interrupted ribs or rows of low, elongate granules or tubercles.

Measurements.—Height, 27 mm.; breadth, 30 mm.; these dimensions representing considerably less than the maximum size. The two largest specimens at hand, though too imperfect for exact measurement, indicate dimensions between one-third and one-half greater.

Occurrence.—Especially abundant, with *Natica williamsi* and other Gasteropoda, in lower strata of the exposed part of the Theta, between the Trio and the Truncate mound, being represented in my collection by 54 specimens.

The species belongs to the subgenus Lissochilus.

NERITA FINLAYENSIS sp. n.

Pl. XIX, fig. 15.

General form somewhat like that of *N. nodilirata*, both body whorl and spire, however, a little more elevated; whorls few; body whorl with an even, obtuse, revolving angulation near the middle, the same being obsolete near the aperture, where the shell is almost evenly

rounded, and gradually becoming noticeable as it recedes from it at half a turn from the aperture; the same angulation apparently continued on the lower part of the spire whorls; base of first spire whorl rising abruptly from the upper margin of the body whorl, the suture thus being strongly indicated; surface of shell devoid of transverse (vertical) ribs or nodes, plain, crossed with finer and coarser growth lines.

Measurements.—Height, about 20 mm.; breadth, 18.5 mm.

Occurrence.—One specimen, obtained in foothills at the northwest end of Malone Mountain, about 2 miles east-southeast from Finlay station.

NERITA PEROBLATA sp. n.

Pl. XIX, figs. 16, 17.

Shell obliquely-depressed oval, consisting of 2 whorls; spire involved, or rising but feebly above the adjoining whorl border; body whorl rapidly increasing its centrifugal expansion with spiral distance from its origin, convex on its outer and lower parts, flattish on an upper zone which is limited below by an obsolescent spiral ridge; aperture semicircular; inner lip without teeth, bearing a thick, flat-surfaced callus; outer lip with simple acute border; surface of shell plain, presenting, besides the obsolescent spiral ridge, only growth lines, some of which, more pronounced than the others and occurring at irregular intervals, constitute coarse constrictions and ridges which are conspicuous also on parts of the cast from which the shell has been removed. Of the outer lip in the type only the lower border is preserved, but this shows the simple and acute character above described.

Measurements.—Height, 41 mm. (of which the spire occupies barely 2); breadth, 44 mm.; height of aperture, 35 mm.; greatest (obliquely centrifugal) diameter of same, 29 mm.

Occurrence.—Known only by one example, which was associated with *Nerita nodilirata*, etc., 1½ miles east of Malone station.

Max Schlosser[a] comments on the Jurassic forms of this genus as follows, translated:

> The Jurassic Neritas are distinguished from the typical by the imperfect (*Nerita chromatica* Zitt.) or wholly obsolete toothing of the inner lip (*Nerita zitteli, neumayri*). The outer lip is always simple with cutting border. As the only departure from this, one observes a greater or less thickening. On the inner lip appears a mostly very strong, often indeed high-arched callus. The general habit, however, agrees so well with the recent forms that the erection of a new subgenus appears inadvisable.

[a] Die Fauna der Kelheimer Diceras-Kalkes: Palaeontographica, vol. 28, p. 93.

TURRITELLIDÆ.

Genus TURRITELLA Lamarck.

TURRITELLA BURKARTI sp. n.

Pl. XX, fig. 5.

Shell turreted, of moderate size for a Turritella, consisting of numerous whorls, which are greatly convex, wider than high, and medially carinate by virtue of the ornamentation, bearing four granulated, revolving raised lines, of which one, much larger and more prominent than the others, and more decidedly cariniform, crosses the middle of the whorl, while 2 of the 3 smaller and subequal ones are placed, respectively, just below and just above the upper and lower limiting suture, the remaining one being placed between the uppermost one and the large carina, and nearer to the former than to the latter, so that the 3 intervals increase serially from uppermost to the lowermost. Aperture unknown.

Measurements.—The type and only known specimen includes four largely embedded whorls within a span of 14 mm. The largest one of these whorls has a height of 4.5 mm. and an exposed breadth of 5.5 mm., which is less than the true breadth, only about a third of each whorl being free from the matrix.

Occurrence.—In the anticline on the east slope of Malone Mountain, nearly 1 mile north of its southern end; collected by Doctor Stanton.

The species is named after a former traveler in Mexico, Mr. Joseph Burkart, who, as quoted from his "Aufenhalt und Reisen in Mexico in den Jahren 1825 bis 1834" by Castillo and Aguilera, on page V of their Fauna Fosil, has recorded a Turritella (identified as to genus by Professor Goldfuss) as collected by him in the Mineral de Catorce some three-quarters of a century ago. The species collected by him may, by no means improbably, have corresponded in geological age and in kind with the Malone species above briefly described.

VERMETIDÆ.

VERMETUS CORNEJOI Castillo and Aguilera ?.

Pl. XX, fig. 6.

Vermetus (*Burtinella*) *cornejoi* Castillo and Aguilera, 1895, Bol. Com. Géol. Mex., No. 1, p. 12, Pl. VI, figs. 5, 6, and 7.

Eight specimens of Vermetus, from the Theta, 1½ miles east of Malone station, are referred to this species. They show only the inner

whorls and only one of them approaches in size the smallest one of the types figured from the Sierra de Catorce by Castillo and Aguilera. The cavity is oval in cross section, and its lesser diameter is equal to about four times the thickness of its wall.

The following is a translation of the specific diagnosis:

Shell small, free in the adult state, tubular, inrolled planorbiform, sinistral, last whorl unrolled. Tube rugose, bearing two spiral carinæ at the base, the exterior more prominent than the interior, inclosing between them a narrow furrow. Aperture circular or slightly oval. Surface furnished with sinuous growth lines and quite pronounced on the upper part of the whorls, less so on the inferior part.

NATICIDÆ.

Genus NATICA (Adanson) Lamarck.

NATICA WILLIAMSI sp. n.

Pl. XX, figs. 7, 8.

Shell of medium size in its genus, imperforate; whorls 5; spire small, short, and concave, giving it an apiculate aspect when well preserved, its height about one-fifth of that of the entire shell; body whorl large, obliquely inverted pyriform, flattish on the region below the weakly impressed suture, the greatest convexity being somewhat above the middle of the whorl; inner lip and columellar region covered with a layer of callus; aperture rather long and narrow, narrowing gradually upward, rounded below, subacute above.

Measurements.—Height, 40 mm.; breadth, about 30 mm. Other specimens, not allowing precise measurement, indicate about one and a half times these dimensions.

Occurrence.—A mile and a half east of Malone station, associated with *Natica inflecta*, *Nerita nodilirata*, etc. At this locality it is one of the commonest of the Malone Gastropoda. Nearly a hundred specimens are in hand, most of them poorly preserved owing to weathering.

This shell is named for Mr. John W. Williams, who in 1897 was prospecting in the Quitman Mountains not far from Malone, and whose exceedingly kind and thoughtful interest in my work, displayed in many practical ways, contributed not a little in that year to the pleasure as well as the success of my explorations in the Malone district.

In its low and concave spire and feebly impressed suture, and a tendency to greater breadth in the upper part of the body whorl, the shell recalls Actæonella and constitutes an unusual phase of Jurassic Amauropsis.

NATICA INFLECTA sp. n.

Pl. XX, figs. 11, 12.

Shell of medium or rather small size in its genus, smaller than *Natica williamsi*, consisting of about 5 whorls, imperforate, of rather stout or medium elevated habit; the spire not concave, much more elevated than that of the above-mentioned species, its height being about two-fifths of that of the shell, composed of convex, well-rounded whorls, separated by sutures which are deeply and rather suddenly impressed, a narrow upper border of the whorls being gently and subhorizontally flattened; aperture narrow, or elevated, considerably less so, however, than that of *N. williamsi*, narrowly rounded below, obtusely pointed above; columella slightly produced, inner lip and spindle callus-plated; surface smooth or crossed only with ordinary growth lines.

Measurements.—Height, 35 mm.; breadth, 27 mm.; height of spire, 14 mm. A second example has dimensions about 75 per cent greater.

Occurrence.—A mile and a half east of Malone station; with *Natica williamsi*, from which the species is readily distinguished. The writer obtained only three shells of *N. inflecta*, one of which, a young example, has the body whorl crossed with alternating dark and light bands, parallel with the growth lines. An example was obtained by Doctor Stanton at the same locality, and one by him in foothills at the northwest end of Malone Mountain, about 2 miles east-southeast from Finlay station.

The species seems to stand close to the English Oxfordian form, *N. arguta* Phil., and is referred to the subgenus Amauropsis, to which all of the Naticæ now known from the Malone formation seem to belong.

NATICA FINLAYENSIS sp. n.

Pl. XX, figs. 15, 16.

Shell of medium size in its genus, subovate, imperforate; whorls about 5, moderately convex, those of the spire broad and low; body whorl large, elevated, oblique; spire more than a third and considerably less than half of the height of the shell, higher than the spire of *Natica williamsi*, lower than that of *N. inflecta;* suture much more strongly impressed than that of the former and much less so than that of the latter species; aperture elevated, arcuate-pyriform, pointed above, rounded below; inner lip not free-margined, and apparently with little callus, concave below, convex above; surface plain.

Measurements.—Height (approximately), 42 mm.; breadth, *30 mm.*

Occurrence.—The type and only known example was obtained by Doctor Stanton in foothills at the northwest end of Malone Mountain, a little over 2 miles east-southeast from Finlay station.

NATICA BILABIATA sp. n.

Pl. XX, figs. 9, 10.

Shell rather small, consisting (apparently) of about 3½ strongly convex whorls; without umbilicus; provided with a narrow, elongate, and shallow cleft formed by the eversion of the inner lip; spire short, its height much less than that of the aperture; suture well impressed; aperture obliquely ovate, about two-thirds as high as the entire shell; outer lip simple; inner lip everted, thickened below, its border quite free in the middle region, where it pursues a nearly straight course and constitutes the outer bound of the small umbilical cleft; exterior smooth except for the numerous ordinary growth lines.

Measurements.—Height, about 21 mm.; breadth 18 mm.

Occurrence.—One specimen, from the same fragment of limestone that bore one of the types of *Unicardium semirotundum;* 1½ miles east of Malone station. Collected by Doctor Stanton.

PYRAMIDELLIDÆ.

Genus PSEUDOMELANIA Pictet.

PSEUDOMELANIA GOODELLII sp. n.

Pl. XXI, fig. 10.

Shell large, turreted, consisting of numerous smooth, flattened, upwardly-imbricated whorls, of which the lower spire whorls are nearly twice as wide as high; shell substance thick, sometimes showing, parallel with the height (length) of the shell, numerous rather narrow, unequal, or subequal, alternating dark and light bands, of which there are perhaps as many as 50 of either shade on each whorl.

Measurements.—Breadth of body whorl in largest specimen, 50 mm.; breadth of first spire whorl, 43 mm.; height of same, 21 mm. The shell in this specimen apparently had a height of 170 to 180 mm. In a second example, with body whorl 44 mm. in breadth, the shell height is about 165 mm.

Occurrence.—This, the largest of the Gastropoda known from the Malone formation, is only moderately common; and all of the material of it obtained is more or less fragmentary, though collectively affording a fair knowledge of the species. The above description of it, based on all of the material now known, supersedes an earlier one in manuscript made by me at a time when my knowledge of the

species was derived solely from an imperfect specimen, which was from the locality 1½ miles east of Malone station. Besides a fragment from the locality just named, Doctor Stanton's collections include material of this shell from the following localities: From No. 13 (the Nautilus horizon) of his Malone Mountain section, on the west side of the mountain, southwesterly from Malone station; and from about 1 mile east of Finlay station, one of the specimens from the last-named locality being in rock with *Trigonia calderoni*. A poorly preserved portion of probably this fossil was also found by Doctor Stanton in the anticline in the eastern slope of Malone Mountain nearly 1 mile north of its southern end.

The species is named after the late Mr. Robert W. Goodell.

NERINEIDÆ.

Genus NERINEA Defrance.

NERINEA GOODELLII sp. n.

Pl. XXI, figs. 1–3.

Shell turriculate to cylindrical-turriculate, not exceedingly attenuate; walls thin, the outer one bearing internally one prominent, thin, and acute fold which extends scarcely half way across the chamber; columella rather slender, in part hollow, bearing 2 thin folds both smaller than the outer fold; whorls apparently 17 or more, low, usually as much as one and a half times and sometimes about twice as wide as high, concave, the opposed borders of successive whorls tending to form a low cariniform ridge with linear suture on the summit line, the surface of each whorl ornamented with 3 or 4 linear, raised, revolving lines and ordinary oblique, somewhat sinuous growth lines. Of the three internal folds, the upper columellar one, which descends from the junction of the upper wall of the chamber with the columella, is the smallest and thinnest, yet is quite salient.

Measurements.—Breadth of largest whorls reaching 14 mm.; angular divergence of slopes 5° or 6° to 8°.

Occurrence.—Common in the limestone layers, and less so in the sandstone, at various levels in the Theta, 1½ miles east of Malone station; exceedingly abundant in some of the lower layers. Weathered-out specimens usually occur in segments of two or three to a dozen or more whorls. Besides the numerous specimens in my collection, which include some natural longitudinal sections, I have examined four specimens, one of which is an artificial section, submitted by Doctor Stanton. Several poor weathered sections were obtained near the south end of Malone Mountain, from a locality which yielded also a specimen of *Trigonia munita*.

I have not been able to ascertain the maximum height of this shell, nor with certainty the number of whorls; but in 1 specimen only 4 mm. in breadth and about 17 mm. in height there are 15 whorls preserved, while probably 2 or 3 minute ones have been dissolved away at the summit.

The revolving lines of ornamentation on this shell are very delicate and commonly are not seen at all on weathered specimens.

In its internal ridges, as well as in the form of its whorls, the species resembles the Corallian form, *N. goodhallii* Sowerby.[a] It is named for the Messrs R. R. and R. W. Goodell, in recognition of their joint exploration of the Malone, an account of which has been given elsewhere.

For comparison with *Nerinea goodellii*, Doctor Stanton has handed the writer some fragments and fragmental prepared sections of a Nerinea "broken from the hand specimen that bears the larger of the types of *Trigonia taffii* Cragin."[b] These resemble *N. goodellii* superficially, but appear to lack revolving lines and to present sectional details which seem to refer them to a different species, although the unsatisfactory state of their preservation forbids full assurance that their internal characters are all correctly understood. In the Nerinea from Bluff Mesa the fold on the outer wall is relatively thicker and more obtuse and is altogether larger than in *N. goodellii*, extending a little more than half way across the chamber; the lower columellar fold is also coarser than that of *N. goodellii*. The upper columellar fold is not very clearly indicated; if present at all it is apparently obsolescent, or at least much smaller than that of *N. goodellii*.

NERINEA CIRCUMVOLUTA sp. n.

Pl. XXI, figs. 4, 5.

Shell cylindrical-turriculate; walls thin, with one outer and two columellar folds situated as in the much more common *Nerinea goodellii*, all of the folds delicate, the outer one less so than the other two; columella solid, rather slender; whorls flat or only very slightly concave, one and a fourth times as high as wide, apparently at least as numerous as in *N. goodellii*, presenting an imbricated appearance at the suture, as if the outer wall of each whorl slightly overlapped

[a] Described and figured in exterior and in section by James de Carle Sowerby, in Dr. William Henry Fitton's "Observations on some of the strata between the Chalk and the Oxford Oölite in the southeast of England;" Trans. Geol. Soc. London, 2d ser., vol. 4, 1836. Sowerby's figures (12 of Pl. XXIII, loc. cit.) represent it as several times larger than the shell here described as *goodellii*. The figures 1294 of the fourth edition of Dana's Manual are partial and much reduced copies of Sowerby's figures, but, unlike the latter, represent the shell as thick-walled.

[b] The large valve from Bluff Mesa, which is the real type of this Trigonia. See remarks on *Trigonia taffii* on page 10.

the whorl next above; suture subtended by a narrow, plain band, which is itself limited below by a delicate striæform groove; surface ornamented only with growth lines, which are for the most part vertical, becoming strongly recurved as they near the upper border of the whorl.

Measurements.—A fragment 6.5 mm. wide at the lower end has 5 whorls in a height of 29 mm.

Occurrence.—The species is based on several segments collected and a longitudinal section prepared by Doctor Stanton, and which are from the locality 1½ miles east of Malone station.

Genus NERINELLA Sharpe.

NERINELLA STANTONI sp. n.

Pl. XXI, figs. 6–9.

In 1898 Doctor Stanton very kindly communicated a specimen of Nerinella, partly cut in longitudinal section, which he had obtained while collecting with me during the previous year from the same beds, 1½ miles east of Malone station, that yielded *Nerinea goodellii*.

It is exceedingly attenuated and, within 53 mm., includes 20 concave whorls from a number that must obviously have been much greater in the complete shell. The chamber has no columellar fold, but its outer wall presents a simple, short, and rather obtuse fold at about mid height. The whorls are crossed by numerous delicate growth lines and are ornamented with 4 equidistant, spiral, cariniform lines on the main part, besides 2 which are so close to the whorl borders as often to be difficultly distinguishable.

I find in my own collection, made 1½ miles east of Malone, a few incomplete and more or less weathered specimens of this fossil. One of these supplements Doctor Stanton's specimen as to the upper part of the spire, showing 16 additional whorls, with apparently a very few still to be added at the apex. Another represents a basal portion considerably broader than the larger end of Doctor Stanton's specimen, so that the number of whorls in this shell can be little, if at all, short of 50. The greatest breadth shown by any of these specimens is between 5 and 6 mm. The height of the shell is roughly estimated at about 100 mm.

This fossil is also recognized in material obtained by Doctor Stanton at the following places: In No. 13 of his Malone Mountain section, about 2 miles southwest of Malone station, on the west of the mountain; in about the same horizon something over 1 mile east of Finlay station, and in the anticline at the east base of the mountain, about a mile from its southern end.

CERITHIIDÆ.

Genus CERITHIUM Adanson.

CERITHIUM ARCUIFERUM sp. n.

Pl. XX, fig. 13.

Shell small, turriculate, many whorled; spindle solid; mouth subquadrate; surface of the gently convex whorls ornamented with numerous fine revolving lines and with coarse transverse folds, or ribs, the latter strongly arched backward, the summit and more prominent portion of the arch being on the lower and more prominent portion of the whorls. Of the revolving lines there are about 17 on the first spire whorl, and of the arcuate folds there are about the same number on the body whorl.

Measurements.—Breadth, 7 mm.; angular divergence of slopes on the lower part of the shell, 21° or 22°.

Occurrence.—A mile and a half east of Malone station; with *Nerita nodilirata*, *Pleurotomaria circumtrunca*, etc. Only a single specimen lacking the lower end of the spindle and the upper part of the spire has been found.

Owing to the incompleteness of the lower extremity of the shell in the type the basal canal is not shown, but its presence in the complete shell and a reference to the genus *Cerithium* are indicated by the character of the spindle and the general habit of the shell, the latter being apparently that of the subgenus *Cerithinella*.

ACTÆONIDÆ.

Genus ACTÆONINA d'Orbigny.

ACTÆONINA ? MALONIANA sp. n.

Pl. XX, fig. 14.

Whorls 4 or 5; body whorl large, about three-fourths as wide as high in the cast, its sides gently convex; spire small, evidently not much exceeding one-fifth of the body whorl in height; aperture high and narrow, somewhat broadened below, and the inner lip apparently without fold; general surface as indicated by a preserved basal fragment, marked with delicate revolving grooves or striæ, the striæ separated by intervals wider than themselves.

Measurements.—Height (approximately), 14.5 mm.; breadth, 10 mm.

Occurrence.—Known only by a cast bearing two fragments of the shell; obtained by Doctor Stanton 1½ miles east of Malone station.

When viewed from above, the cast presents a somewhat squared form, due apparently to the accident of rock pressure.

CEPHALOPODA.

NAUTILOIDEA.

Genus NAUTILUS Breyn.

NAUTILUS BURKARTI C. and A. ?

Pl. XXII, fig. 1.

Nautilus burkarti Castillo and Aguilera, 1895, Bol. Com. Geol. Mex., No.1, p. 12, Pl. XXI, fig. 3.

I provisionally refer to this species an imperfect specimen of Nautilus of inflated form obtained by Doctor Stanton in No. 13 of his Malone Mountain section, on the west side of the mountain southwest of Malone station. The dimensions are much larger than those indicated by Castillo and Aguilera's figure and description of *N. burkarti*, which are perhaps those of a young example.

The Malone Mountain specimen gives the following measurements: Height of shell, 123 mm.; height of last whorl, 67 mm.; breadth of the latter, as restored, 86 mm. The height of the last whorl is therefore about 54.5 per cent and its breadth about 70 per cent of the height of the shell, as against 55 and 64, given as corresponding percentages for the type-specimen.

The following is a translation of the original description of the species:

Shell extremely inflated; spire composed of few whorls which cover more than three-fourths of the whorls preceding; flanks quite convex and attaining their greatest thickness near the umbilicus, whence they descend gradually toward the siphonal region, which is quite rounded; umbilicus narrow, deep, and funnel-shaped; aperture very much invaded by the spire whorl, wider than high, rounded on the upper part; surface nearly smooth, destitute of tubercles, bearing only marked growth lines, which make it slightly rough on some parts.

Diameter	49.00 mm.
Breadth of the last whorl in relation to the diameter	.55
Thickness of the last whorl in relation to the diameter	.64
Diameter of the umbilicus to the diameter	.23

NAUTILUS NAUFRAGUS sp. n.

Pl. XXIII, fig. 3, Pl. XXIV, fig. 3.

Shell involute, somewhat compressed; volutions deeply embracing, *increasing* rapidly in size, narrowed on the feebly convex flanks from

a region of maximum, yet moderate inflation, near the umbilicus to the rather narrowly rounded periphery; septa about 24 to each turn, the sutures feebly waved or sigmoid; umbilicus narrow, filled with a shelly columella; surface of shell smooth. The position of the siphuncle has not been determined.

Measurements.—The greatest diameter of the larger specimen is about 122 mm. The height of the largest preserved part of the body-chamber in its median plane is about 50 mm. The height of the same part of the body-chamber over all, or measured on a tangent to the flank from the level of its umbilical border to the level of the periphery, is about 71 mm. (66 on one flank, 76 on the other flank, in the specimen as preserved, the umbilical axis having an oblique position, due to crushing). The original breadth of the same part of the body chamber, allowing for crushing, was apparently not less than 60 mm.

Occurrence.—Two imperfect specimens of this shell were collected by Doctor Stanton in foothills near the railroad, at the northwest end of Malone Mountain, about 2 miles east-southeast from Finlay station, the horizon not more than 200 feet above the gypsum bed.

AMMONOIDEA.

Genus OPPELIA Waagen.

OPPELIA ? FALLAX (C. and A.).

Pl. XXII, figs. 2, 3.

Placenticeras fallax Castillo and Aguilera, 1895, Bol. Com. Geol. Mex., No. 1, p. 17, Pl. VIII, figs. 1, 2.

This large, plain, compressed, and obtusely lenticular ammonite is rather common in the limestone portions of Theta subdivision of the Trio section, 1½ miles east of Malone station, but has been obtained thence in fragmentary specimens only.

The following is a translation of the original specific description:

Shell compressed, narrowly umbilicate. Spire composed of not very numerous embracing whorls, which almost completely hide the previous whorls. Flanks feebly convex, descending gradually toward the umbilical border and with the same regularity toward the siphonal region, which is rounded and a little more narrow than the flanks; the greatest thickness of the shell is on the umbilical border. Umbilicus very narrow and deep, with vertical walls, with uncarinated border. Aperture very high, considerably invaded by the spire whorl, rounded in the upper part, of nearly elliptical form. Surface of the shell smooth on the last whorls, bearing in the earlier whorls fine lines of growth. Diameter, 104 mm.; breadth of the last whorl in relation to the diameter, 0.54; thickness of the last whorl in relation to the diameter, 0.32; diameter of the umbilicus in relation to the diameter, 0.16.

To the above description Castillo and Aguilera add the following remarks:

We place this species in the genus *Placenticeras*, notwithstanding that by its form it could be considered as a *Phylloceras*, by the characters of the sutural line which, though imperfectly visible in one of the specimens of our collection, does not present the saddles terminated by the roundels characteristic of the *Phylloceras*, only ramifications and subdivisions similar to those of the *Placenticeras*.

As it makes some departures from the characters belonging to most of its congeners, this ammonite may seem at first sight almost as much of an anomaly in the genus *Oppelia* as it was supposed to be in *Placenticeras*. But the suture, which has the lobes and saddles very few instead of many,[a] and has the first lateral lobe contrastingly the largest, sufficiently distinguishes it from the latter genus and relates it to *Oppelia* and *Haploceras*, with which also agree its involute, narrowly umbilicated shell, its rounded venter, its rather compressed lenticular form, and the absence of periodical constrictions. It seems indeed to have its closest affinities and to belong among the round-ventered, phylogerontic forms of *Oppelia* which occur in the latest Jurassic rocks, in which this genus makes its final appearance; the venter, in *O. fallax*, being rounded both on the outer and on the inner whorls.

The Malone *Oppelia* bears considerable resemblance to the Tithonian species, *O. waageni* Zittel, having about the same outward form and being of large size; but it apparently lacks a vestige of even such feebly expressed, coarse lateral ribs, or undulations, as are seen on that shell, and is more critically distinguished from it by the characters of the suture. The first lateral saddle is much narrower in the Malone ammonite than in *Oppelia waageni*, and the first lateral lobe—which is quite unsymmetrically branched in the latter shell—presents an almost symmetrical branching in *O. fallax*. In this last-mentioned character, *O. fallax* departs from the condition most common in *Oppelia* and approaches the usual condition in *Desmoceras*, from which genus it is separated by the absence of constrictions. The siphonal lobe is about half as long as the first lateral lobe and ends in two small branches on either side.

Though commonly represented from the Malone district by whorl fragments of dimensions not or little exceeding those given by Castillo and Aguilera for the examples from the Sierra de Catorce, the shell attains a much larger size. One specimen, of which considerable portions were collected 1½ miles east of Malone station, has in the largest preserved cross section of the body chamber, a height of about 145 and a breadth of at least 93 mm., while the diameter of

[a] *My attention was first called to the few-lobed suture, as inconsistent with Placenticeras, by Doctor Stanton.*

the coil (a large part of whose periphery is preserved) must have considerably exceeded a foot. The specific identification is tentative, as it is based on the comparison of imperfect specimens with Castillo and Aguilera's description and figures. The specimen figured is a young individual and the only one in the collection that shows more than a fragment of a complete volution.

Genus OLCOSTEPHANUS Neumayr.

OLCOSTEPHANUS MALONIANUS sp. n.

Pl. XXIV, figs. 1, 2.

Shell large and moderately involute, consisting of massive whorls which are at least as high as or a little higher than wide, with flattish-convex flanks and broadly rounded periphery, about one-fourth of the height of each inner whorl embraced within the whorl next outer; umbilical costæ not at all resembling compressed tubercles, but heavy, long, and truly rib-like, traversing the lower and middle parts of the flank from the lower border to between half and two-thirds the height of the whorl, giving place at their upper ends to numerous compressed, narrowly round-topped costellæ which are fascicled mostly in threes at their origin, but are uniformly distributed upon the periphery of the whorls, over which they pass without interruption, swinging very little forward; suture strongly dissected, the two lateral lobes and saddles large and complexly branching, the external one especially so. The body chamber is unknown.

Measurements.—The largest known whorl section (which is in the septate portion of the shell) has the height and breadth about 110 and 105 mm.; an inner one about 58 and 57 mm., respectively.

Occurrence.—Only a few parts of whorls, most if not all of which belong to one specimen, were collected at the locality 1½ miles east of Malone station.

The species is intermediate in general proportions between the two species of *Olcostephanus* known from the Alamitos beds—which seem to correspond in some measure with the Malone formation—in Mexico: *O.* "af. *portlandicus* de Loriol" and *O. potosina* of Castillo and Aguilera.

Genus PERISPHINCTES Waagen.

PERISPHINCTES CLARKI sp. n.

Pl. XXIX, figs. 1, 2.

Shell large, discoidal, many whorled, broadly umbilicated; involution more than one-half; whorls ovate, the outer ones elevated or narrow-ovate in cross section, narrowed toward the venter, which is

rather narrowly rounded; the flanks flattish-convex; umbilical border rounded; the wall of the outer whorl sloping rather gently to the next whorl within it, that of the inner whorls descending somewhat more steeply below; inner whorls ornamented with strongly elevated, moderately close, but not crowded, dichotomous ribs whose branches separate at about the middle of the flank and continuously cross the venter, the lateral ribs not noticeably enlarged on the umbilical border, this ornamentation becoming gradually changed to large low undulations on the outer whorls and almost vanishing before the (presumably plain or nearly plain) body chamber is reached; septal line with two strong lateral lobes, which are rather strongly dissected, and a deep suspensive lobe; the first lateral lobe large, twice or more than twice as long as the second, longer than the siphonal lobe, and having three strong terminal branches of which the outer is subtended by a smaller branch; the second lateral lobe pinnate, not distinctly branched at summit; a noticeable lobe, similar to the second lateral lobe, but slenderer and about two-thirds as long, stands between the first lateral and the siphonal lobe; suspensive lobe consisting of one tall pinnate lobe, with strongly trifid summit, which is outwardly preceded by a trio consisting of a small lobe flanked on either side by a lobule and is inwardly followed by two obtuse lobes the inner of which is very low and often 3-denticled. This description of the septal line relates to the later septa, the preceding ones being somewhat simpler.

Measurements.—Height of largest cross section of whorl preserved in the type, 85 mm.; breadth of same, 54 mm.; span of umbilicus opposite same section, 90 mm.

Occurrence.—The type represents a considerable and wholly septate part of the form and was obtained by Doctor Stanton from No. 13 of his Malone Mountain section on the west side of the mountain, about 2 miles southwesterly from Malone station. He obtained a fragment also on the east slope of the mountain near its southern end, about 200 or 300 feet above the heavy bed of gypsum which there forms the base of the mountain; and a poorly preserved specimen and fragment from foothills near the railroad, at the northwest end of Malone Mountain, a little over 2 miles east-southeast of Finlay station, not more than 200 feet above the gypsum bed of that locality.

It is not unlikely that this is the same species as that figured and briefly described from the Tithonian of Mexico as "*Perisphinctes sp.* (?)" by Castillo and Aguilera,[a] and compared by them in its ribbing with *P. lictor*, *P. haliarchus*, and *P. polygyratus*. The septal line bears considerable resemblance to that of the latter species, which, from the White Jura Beta, Quenstedt[b] figures under the name of "*Ammonites triplicatus albus.*"

[a] Fauna Fosil de la Sierra de Catorce, p. 35, Pl. XIX.
[b] Die Ammoniten des Schwäbischen Jura, pl. 100, fig. 8.

The species is named for Dr. Wm. Bullock Clark, professor of geology in Johns Hopkins University and director of the Maryland geological survey.

PERISPHINCTES AGUILERAI sp. n.

Pl. XXVIII, figs. 1, 2.

Shell large, discoidal; umbilicus large, spanning more than a third of the diameter of the shell, rather shallow, its wall descending almost vertically from a rounded border; whorls little involute, each concealing only between a fourth and a fifth of its predecessor, about three-fourths as broad as high, broadest in the lower third, their flanks flattened-convex, the venter rounded, apparently a little tectiform on the outer whorl; ornamented with very numerous compressed ribs, which arise independently at the umbilicus, have a somewhat backward inclination in ascending the umbilical wall, and cross the flanks with a gentle forward inclination and slight sigmoid flexure, bifurcating at about the mid flank into parallel branches that sweep strongly forward on the ventral region so that those of opposite sides meet on the periphery at nearly a right angle; the ribs, and especially the ventral ones, close, yet narrower than the round-bottomed intervals between them, the ventral ribs of the inner whorls being very fine, those of the outer whorls large, though still compressed and strongly elevated; septal line strongly dissected, apparently not differing from that of Perisphinctes, though hitherto observed only in part, the saddles at least not ending in roundels such as characterize the Phylloceratidæ.

Measurements.—Outer whorl attaining at least a height of 107 mm. and a breadth of 84 mm. The cross section of a smaller whorl has the same dimensions, 57 and 50 mm.

Occurrence.—Seven fragments of this species were obtained by Doctor Stanton from the foothills west of Malone Mountain, about 2 miles north of the southern end of the latter. The horizon is regarded by him as probably the same as one that yielded him specimens of the *Exogyra*, herein identified as *E. potosina* (narrow phase).

The species is named for Señor José G. Aguilera, director of the geological institute of Mexico.

PERISPHINCTES POTOSINUS C. and A.

Pl. XXIII, fig. 1.

Perisphinctes potosinus Castillo and Aguilera, 1895, Bol. Com. Geol. Mex., No. 1, p. 31, Pl. XVII, fig. 1 and Pl. XXIV, fig. 2.

Among the specimens from the locality 1½ miles east of Malone station is a fragment of a Perisphinctes belonging to the series of

P. contiguus Catullo, and that seems to agree sufficiently with the description and illustrations of *P. potosina* C. and A. The lateral ribs, in form, size, interspacing, and manner of trifurcation, are those of *P. contiguus*, from which the Malone sheil differs in the more anteriorly inclined lateral ribs and in having the ventral ribs distinctly curved forward as they approach the periphery, on which they are slightly extinguished. The last-named feature, however, is not a specific difference; for while the ventral ribs in *P. contiguus* are usually uninterrupted, a slight peripheral attenuation of them is noted by Toucas[a] as occurring in some varieties of this species in the Carpathians.

The fragment agrees in size with an intermediate part of the outer whorl of *P. contiguus* or *P. potosinus*, and the cross section of whorl which it indicates is about three-fourths as broad as high, measuring 24 mm. in height and 18 or 19 mm. in breadth.

Siemiradzki[b] refers to *P. potosinus* as apparently identical with *P. kokeni* Behrendsen,[c] but there seem to me to be considerable differences between the two species. These differences, if we accept the description and the figure of the adult (Pl. XVII, fig. 1) and exclude the smaller and doubtfully pertinent figure (Pl. XXIV, fig. 2) given by Castillo and Aguilera of their *Perisphinctes potosinus*, are as follows:

P. kokeni.	*P. potosinus.*
Involution ½.	Involution ⅔ to ¾.
Whorls broader (thicker) than high.	Whorls higher than broad.
Whorl cross section quadrilaterally rounded.	Whorl cross section flat-sided ovate.
Venter flatly rounded.	Venter rounded.
Lateral ribs bifurcate.	Lateral ribs bifurcate, the larger number becoming trifurcate on the last whorl.
Simple part of lateral ribs rather slender.	Simple part of lateral ribs rather stout.

PERISPHINCTES FELIXI C. and A.

Pl. XXIII, fig. 2.

Perisphinctes felixi Castillo and Aguilera, 1895, Bol. Com. Geol. Mex., No. 1, p. 25, Pl. XVI, fig. 1.

A species of Perisphinctes apparently not distinct from *P. felixi* C. and A., but intermediate in some of its characters between the latter and the closely allied, if indeed really distinct *P. lauri* C. and A., is represented from the locality 1½ miles east of Malone station by a specimen showing part of three successive whorls.

The whorls are rounded in cross section, having their height and

[a] Bull. Soc. Geol. France, 3d ser., Vol. XVIII, p. 582.
[b] *Monogr.* Beschr. Perisphinctes, p. 170.
[c] *Zeitschr. d. Deutsch.* Geol. Gesellsch., Bd. 43, p. 406, pl. 24, figs. 1 and 2. 1891.

breadth about equal (25 mm.), yet having their greatest breadth in the lower part. The involution is between ⅓ and ½. The ribs are heavy and inclined forward; mostly bifurcate at about the middle of the flank, but in one instance a rib is seemingly bidichotomous, the first bifurcation taking place on the umbilical border. The ventral ribs pass over the periphery without interruption, but are curved forward as they approach the median line so as to make a very obtuse angle, at which many of them suffer a very slight weakening. The specimen does not show the largest part of the last whorl, a fact to which the almost uniformly bifurcate character of the ribbing is probably due.

Doctor Stanton also has collected at this locality a small specimen that apparently represents the inner whorls of the same species. This has many of the ribs once bifurcate, the others simple.

The following is a translation of the original description of the species:

Shell discoidal, spire composed of embracing whorls of nearly round cross section, visible in the umbilicus in a third of its width, having its major thickness near the umbilical border; flanks convex, descending gradually toward the umbilicus; siphonal region perfectly rounded. Umbilicus small, rather deep, its border not angulated. Surface covered with 46 to 48 strong, equal costellæ which bifurcate, some at the middle of the flanks and others a little earlier; of the former some trifurcate and the latter undergo a second bifurcation, which takes place at the same distance from the umbilicus as that of the other costellæ; three or four ribs remain simple; all cross the siphonal region forming a slight forward inflection. Aperture a little higher than wide, a little invaded by the whorl of the spire and rounded above. Three narrow constrictions [*surcos*] are seen, shallow and parallel to the costellæ. Diameter 60 mm., 75 mm.; breadth [height] of the last whorl with relation to the diameter 0.38, 0.38; thickness of the last whorl with relation to the diameter 0.38, 0.38; diameter of the umbilicus with relation to the diameter 0.35, 0.33.

PERISPHINCTES SCHUCHERTI sp. n.

Pl. XXV, fig. 1; Pl. XXVI, figs. 1–3; Pl. XXVII, fig. 1.

Shell discoidal, moderately involute, each whorl embracing about a third of its predecessor: the umbilicus strongly excavated, its span equaling about a third of the corresponding diameter of the shell: whorls laterally compressed, even the earlier ones being much higher than wide, the flanks flattened-convex, narrowed toward the siphonal side, which is rounded, umbilical border rounded above, descending almost sheerly below to the surface of the inner whorls; septal line with two lateral lobes, of which the first is large, ample-trunked and longer than the siphonal lobe, and ends in three branches, the second lateral lobe being well developed and considerably more than half as long as the first, suspensive lobe (*nahtlobus*) of intermediate steepness, presenting one conspicuously large auxiliary lobe; ribs gently

inclined forward on the flanks, somewhat enlarged on the umbilical border, those of the earlier whorls very close and bifurcating or sometimes trifurcating at about the middle of the flank into feebly diverging smaller ones, an occasional rib remaining simple and then being usually accompanied by a short, independent rib, corresponding with one of those produced by bifurcation, this ornamentation becoming gradually obsolete on the greater part of the height of the flanks and also on a narrow median zone in the more mature portion of the shell, which portion is also usually encircled with large shallow constrictions at remote intervals; the ventral ribs about equal to the intervals between them.

Measurements.—The maturer aspects of the shell are represented only by fragments; the cross section of one of which has a height of 47 mm. and a breadth of 27 mm.

Occurrence.—The type material consists of several imperfect specimens and various fragments, all collected by Doctor Stanton in foothills near the railroad, at the northwest end of Malone Mountain, about 2 miles east-southeast of Finlay station. Material obtained on the west side of Malone Mountain, from No. 13 of Malone Mountain section, includes a very doubtful fragment of this species from about 2 miles west of Malone station, and a specimen, also doubtful, and a fragment from a point about three-fourths of a mile farther south. That collected 1½ miles east of Malone station includes a fragment which not improbably belongs to this species.

The septal line of *P. schucherti* is of the same general pattern as that of *P. inconditus* Font., as figured by de Loriol,[a] but differs from it by its broader first lateral lobe and in other details. The shell of *P. schucherti* also differs from that of *P. inconditus* in that the latter has trifurcate and even sometimes quadrifurcate ribs, the ribbing on the flanks of the inner whorls being very much closer in *P. schucherti* than in either *inconditus* or *balderus*.

The second specimen above mentioned is larger and less compressed than the others and has the ribs less inclined forward on the venter, and on part of the shell almost radially directed. I am uncertain whether it belongs to *P. schucherti* or is the young of a larger species. The ribs are, however, obsolete on the flanks, and the specimen is therefore referred here provisionally. It gives the following measurements: Greatest diameter, 125 mm.; span of umbilicus, 50 mm.: height of outer whorl in intermediate part, 45 mm.; breadth of same, 30 mm. It is without constrictions, and in form and character of ventral ribbing bears a resemblance to *Olcostephanus potosinus* C. and A., a fossil from which in other respects it widely differs.

The species is named for Mr. Charles Schuchert, curator of invertebrate paleontology in the United States National Museum.

[a] Foss. d. Baden, Pl. XI, fig. 1c.

Genus ASPIDOCERAS Zittel.

ASPIDOCERAS ALAMITOCENSIS C. and A.

Pl. XXVII, fig. 2.

Aspidoceras alamitocensis Castillo and Aguilera, 1895, Bol. Com. Geol. Mex., No. 1, p. 43, Pl. XXIII.

A portion of a shell which appears quite identical with this bulky ammonite was obtained 1½ miles east of Malone station. It includes about a fourth of a volution, belonging mostly to the septate part of the shell, but including also a small posterior fraction of the body chamber. The septal line is imperfectly shown, but the lateral lobes and saddles are large and coarsely dissected, the saddles having obtuse, the lobes having sharply pointed terminal divisions; and the auxiliaries (not visible in our specimen) are few, or at least not present beyond a narrow umbilical tract of the whorl. Of the two rows of tubercles, only one—that which borders the umbilicus—is shown, owing to the condition of the specimen. Traces of low ribs separated by broad and shallow valleys and crossing the broadly rounded outer side of the whorl, are distinguishable. The specimen indicates a shell at least as large as the largest of the Alamitos specimens whose dimensions are given by Castillo and Aguilera. In the matrix with it are several imperfect specimens of *Exogyra subplicifera*.

VERTEBRATA.

As compared with the rich invertebrate fauna, the known vertebrate fauna of the Malone formation is pitifully meager.

Besides a few ill-preserved and problematical structures which may pertain to Vertebrata, the Malone Hills, 1½ miles east of Malone station, have yielded two cycloid fish scales, between circular and quadrate in outline and a little smaller in area than a 1-cent piece; one well-preserved hemispherical tooth, about the size of a checkerberry, of a Pycnodont; and a number of fragments of bones of rather large swimming reptiles, which are probably in part those of Enaliosaurs.

The east slope of Malone Mountain, a mile north of its southern end, has yielded Doctor Stanton a shark's spine of indeterminate genus.

While the Upper Jurassic rocks of Potosi, Oaxaca, etc., Mexico, have yielded a considerable number of invertebrates—some now known, others not yet known, from Texas—they have apparently yielded no vertebrate remains of record whatsoever; and the above brief notices therefore apparently embrace all that is known of the Vertebrata of the Upper Jurassic in Texas and Mexico.

PLATES.

PLATE II.

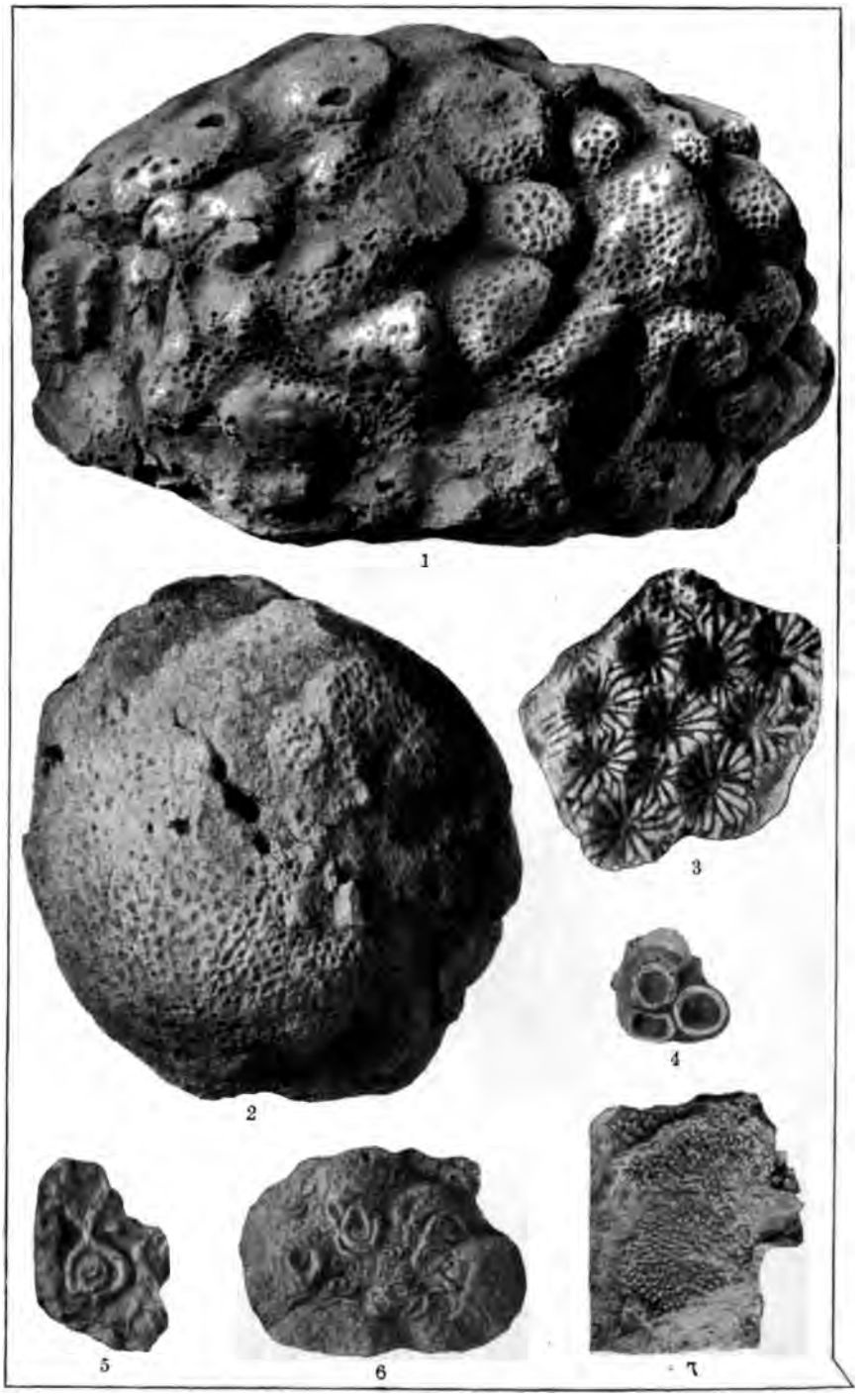
PLATE II.

FIGS. 1–3. ASTROCŒNIA MALONIANA Vaughan, sp. n. (p. 34).
Figs. 2, 3. Coralla of natural size showing variation in mode of growth.
Fig. 3. Several corallites from fig. 2, enlarged 6 diameters.

FIG. 4. SERPULA sp. (p. 37).
Cross sections of tubes.

FIGS. 5, 6. SERPULA GORDIALIS Schlotheim (p. 37).
Several specimens growing on Astrocœnia maloniana.

FIG. 7. BERENICEA MALONIANA sp. n. (p. 38).
Enlarged 3 diameters.



MALONE JURASSIC INVERTEBRATES.

PLATE III.

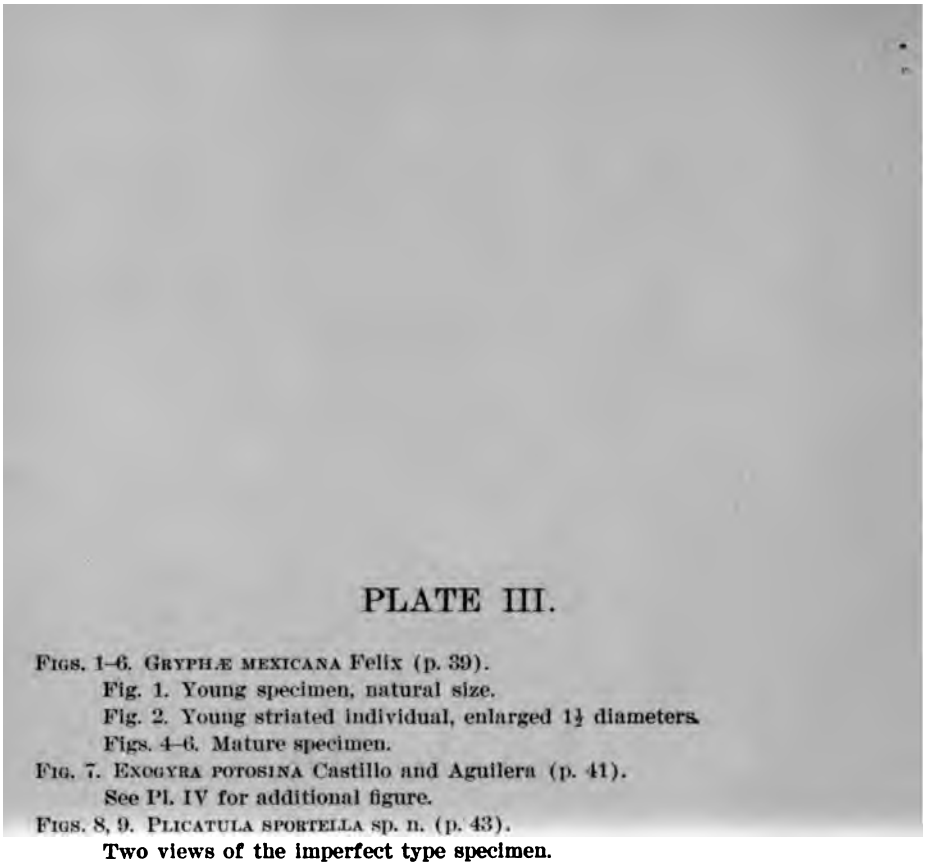
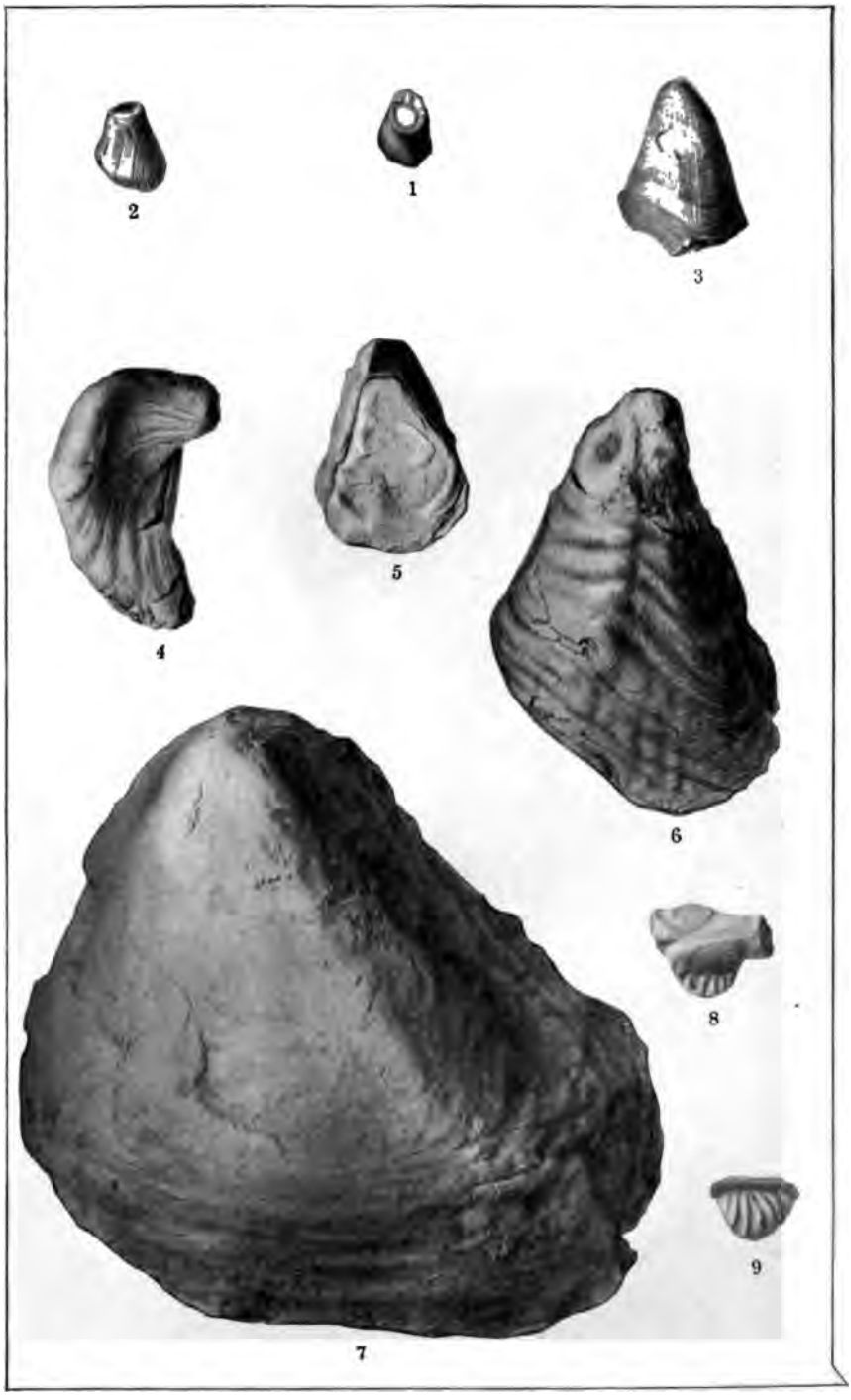


PLATE III.

FIGS. 1–6. GRYPHÆ MEXICANA Felix (p. 39).
Fig. 1. Young specimen, natural size.
Fig. 2. Young striated individual, enlarged 1½ diameters.
Figs. 4–6. Mature specimen.
FIG. 7. EXOGYRA POTOSINA Castillo and Aguilera (p. 41).
See Pl. IV for additional figure.
FIGS. 8, 9. PLICATULA SPORTELLA sp. n. (p. 43).
Two views of the imperfect type specimen.



MALONE JURASSIC INVERTEBRATES.

PLATE IV.

PLATE IV.

FIGS. 1–4. EXOGYRA SUBPLICIFERA Felix (p. 41).

FIGS. 5, 6. LIMA INTERLINEATA sp. n. (p. 43).

Fig. 5. Type specimen, natural size.

Fig. 6. Part of sculpture, enlarged 3 diameters.

FIG. 7. EXOGYRA POTOSINA Castillo and Aguilera (p. 41).

See Pl. III, fig. 7.

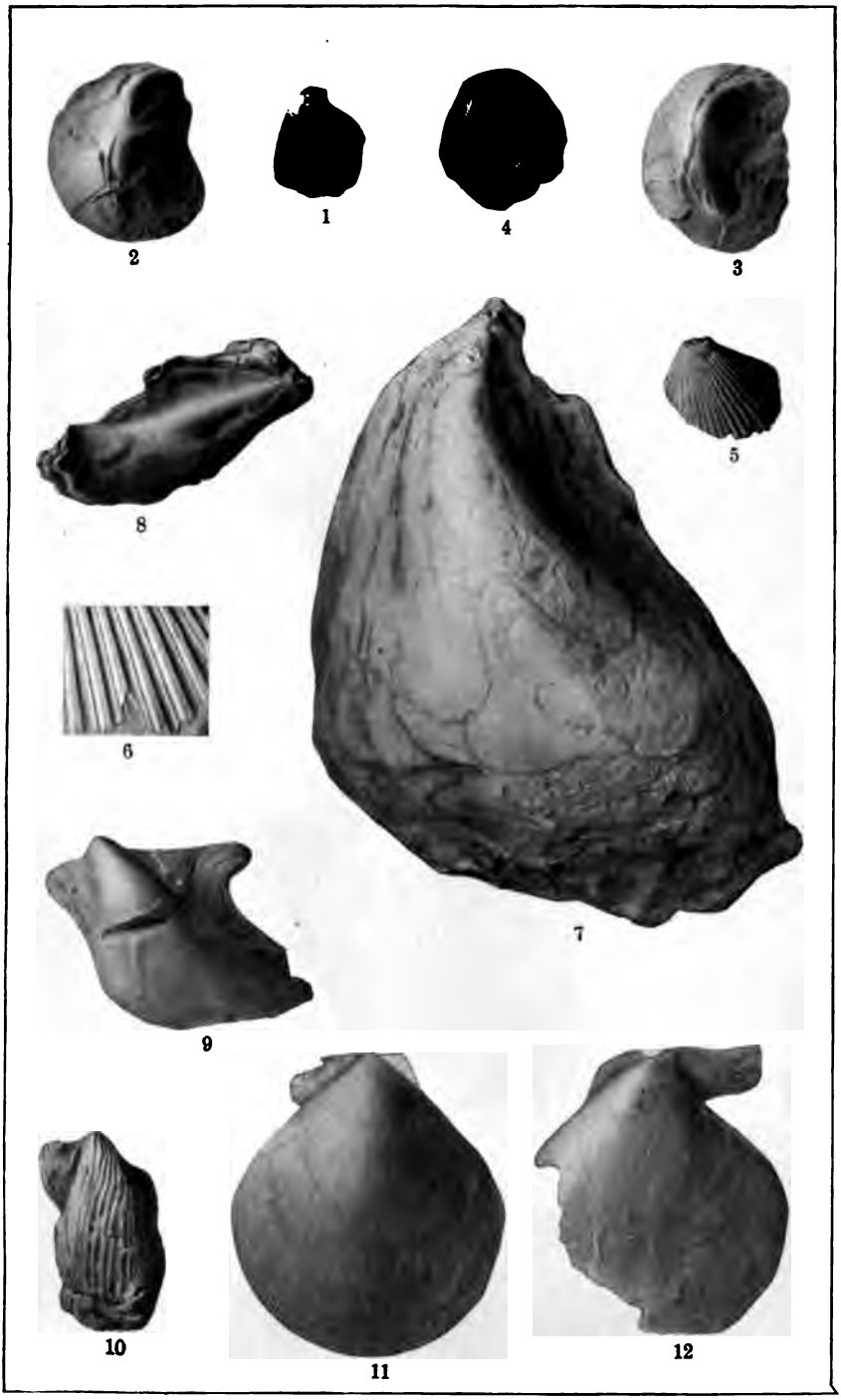
FIGS. 8, 9, 10. GERVILLIA CORRUGATA sp. n. (p. 46).

Fig. 8. Right valve with most of the shell exfoliated.

Fig. 9. Left valve of another specimen in same state of preservation.

Fig. 10. Small distorted left valve showing strong sculpture of umbo.

FIGS. 11, 12. PECTEN INSUTUS sp. n. (p. 44).



MALONE JURASSIC INVERTEBRATES.

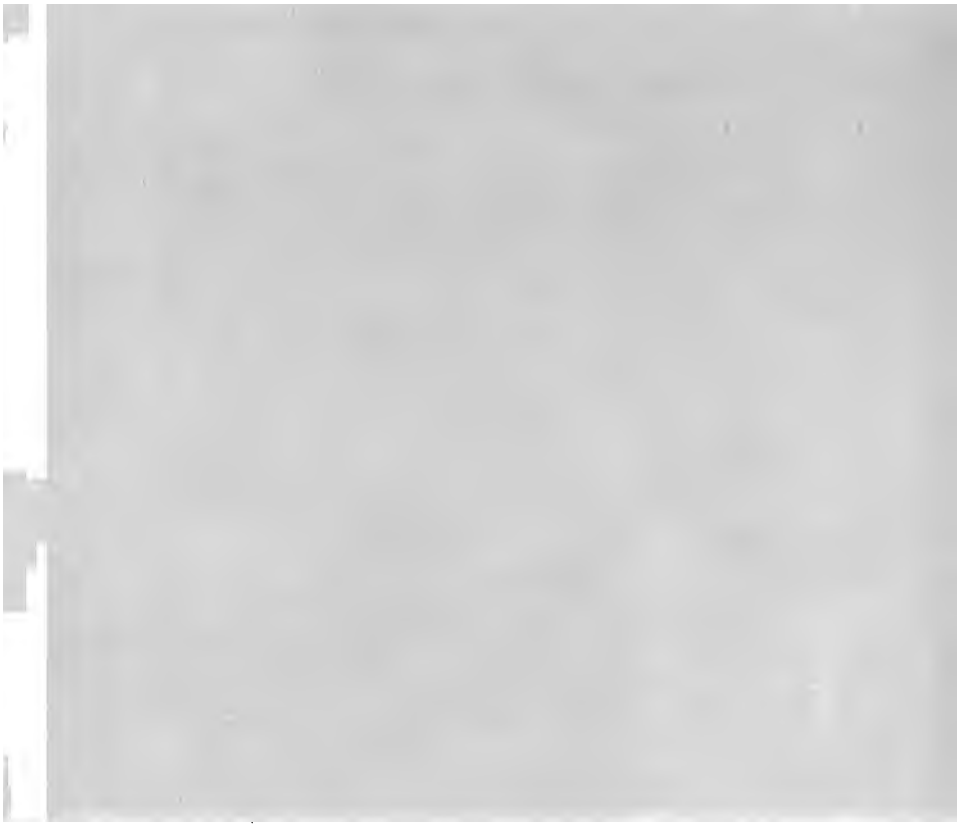
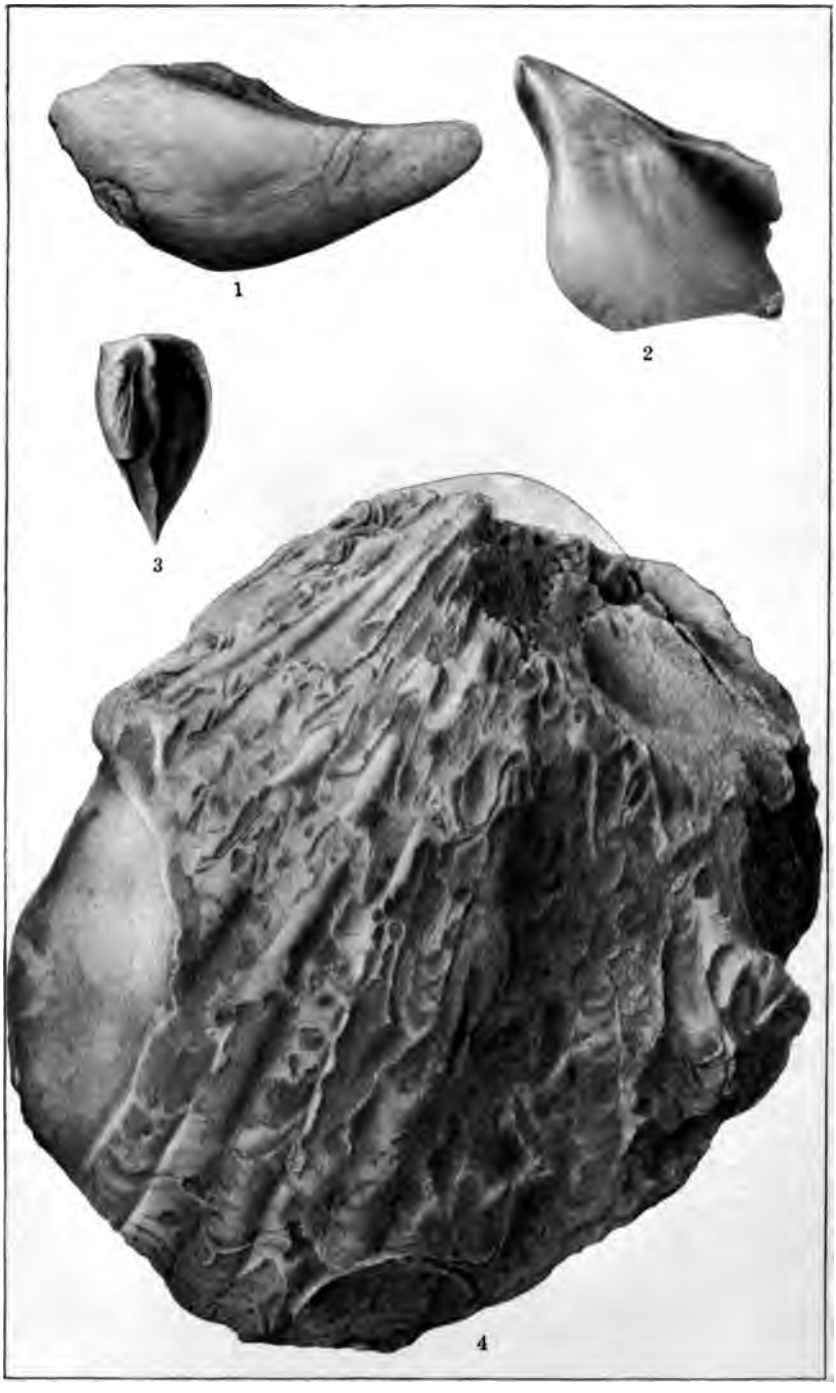


PLATE V.

PLATE V.

FIG. 1. GERVILLIA CINDERELLA sp. n. (p. 47).
FIGS. 2, 3. GERVILLIA ? RIOGRANDENSIS sp. n. (p. 47).
Side and profile views of the type specimen.
FIG. 4. LIMA (CTENOSTREON) RIOGRANDENSIS sp. n. (p. 44).



MALONE JURASSIC INVERTEBRATES.

PLATE VI.

PLATE VI.

FIGS. 1, 2. MODIOLA MALONIANA sp. n. (p. 48).
Side and profile views of the type specimen.
FIG. 3. MODIOLA GENICULATA sp. n. (p. 49).
FIGS. 4, 5. MYTILUS NUNTIUS sp. n. (p. 48).
Side and profile views of the type specimen.
FIG. 6. ARCA DUMBLI sp. n. (p. 51).
FIGS. 7, 8. ARCA TAFFII sp. n. (p 50).
Side and profile views of the type specimen.
FIGS. 9, 10. CUCULLÆA ? TEXICOSTATA sp. n. (p 52).
Fig. 9. The imperfect type specimen.
Fig. 10. Portion of surface enlarged.
FIGS. 11, 12. CUCULLÆA CASTILLOI sp. n. (p 54).
Side and profile views of the type specimen.
FIG. 13. LEDA ? NAVICULA sp. n. (p. 55).

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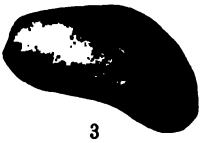

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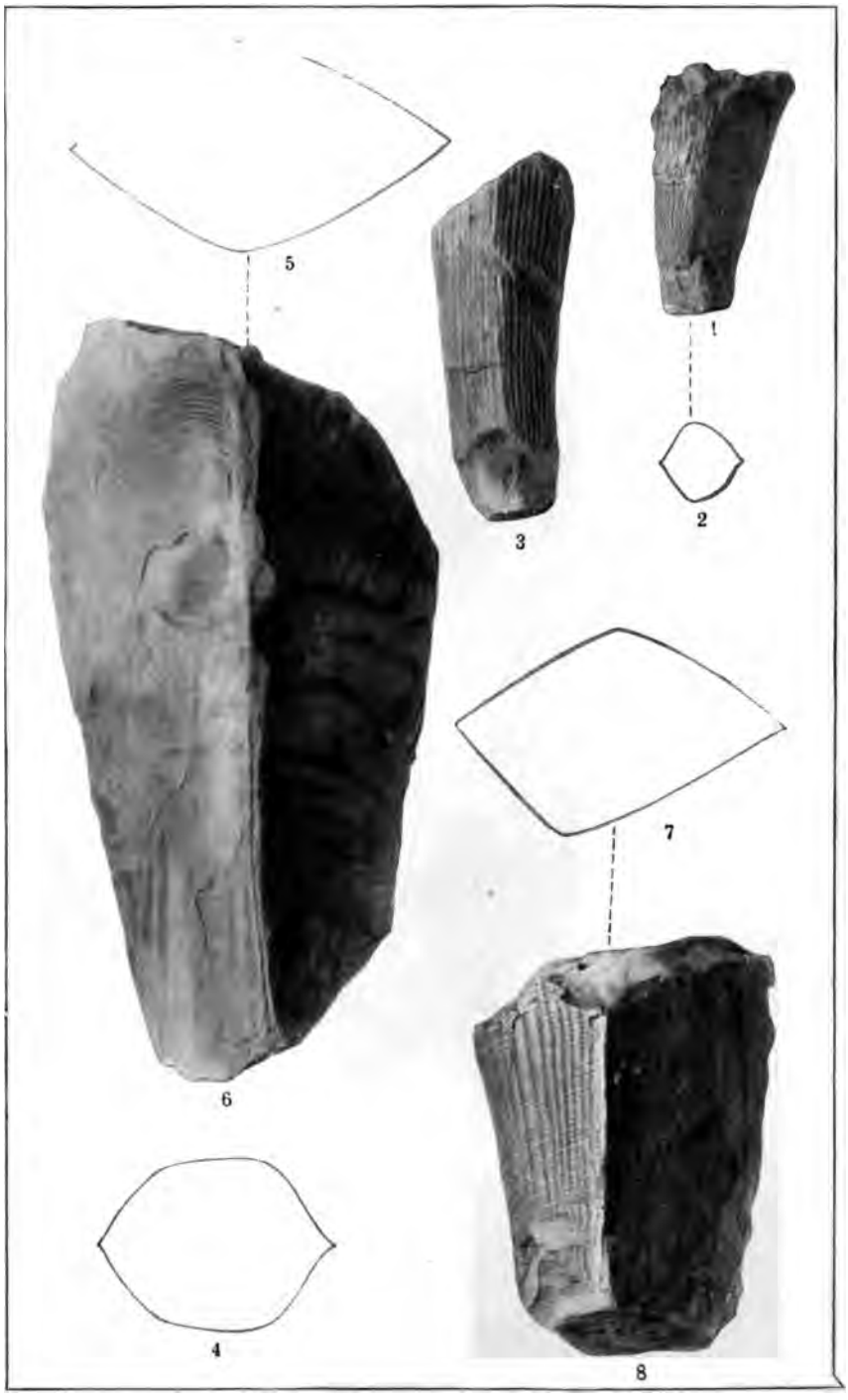
MALONE JURASSIC INVERTEBRATES.

PLATE VII.

PLATE VII.

FIGS. 1–8. PINNA QUADRIFONS sp. n. (p. 49).



MALONE JURASSIC INVERTEBRATES.

PLATE VIII.

PLATE VIII.

FIGS. 1, 2. TRIGONIA VYSCHETZKII Cragin (p. 56).
See Pl. IX, fig. 3, for anterior view of specimen represented by fig. 1.

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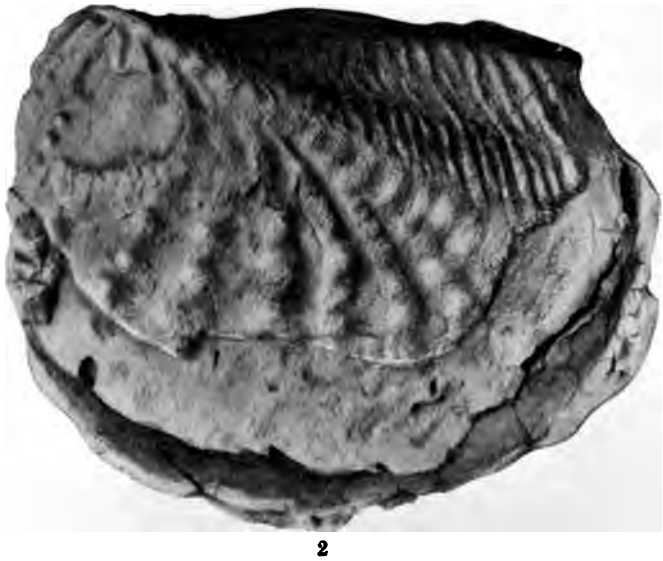

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MALONE JURASSIC INVERTEBRATES.

PLATE IX.

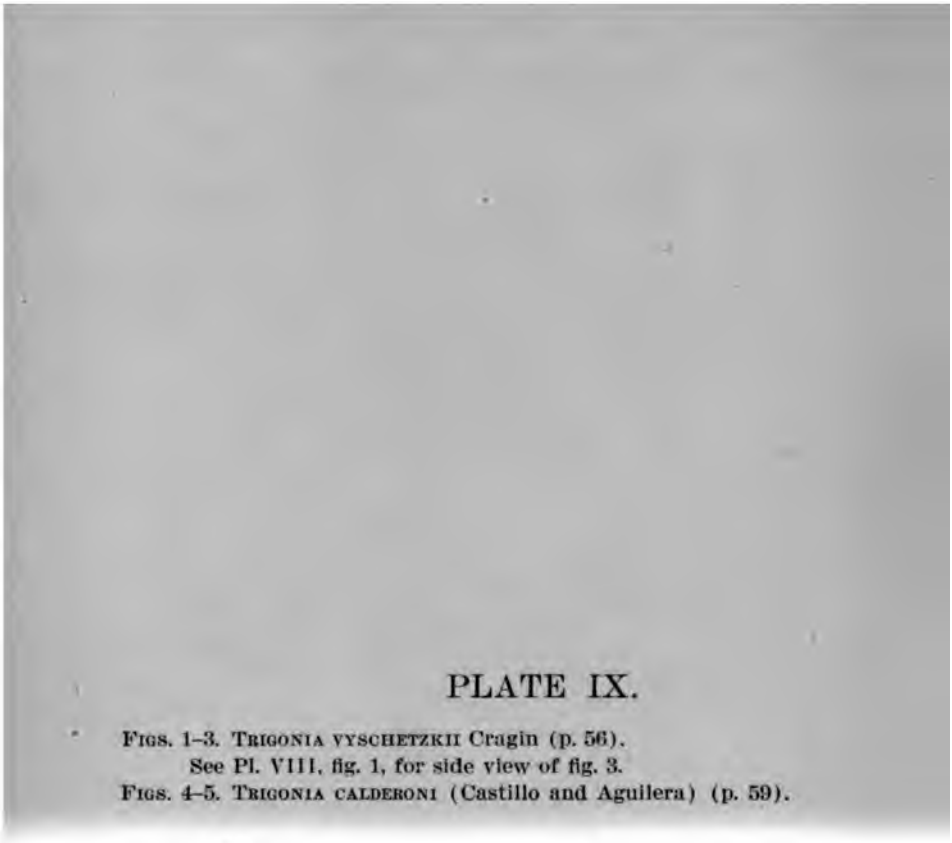
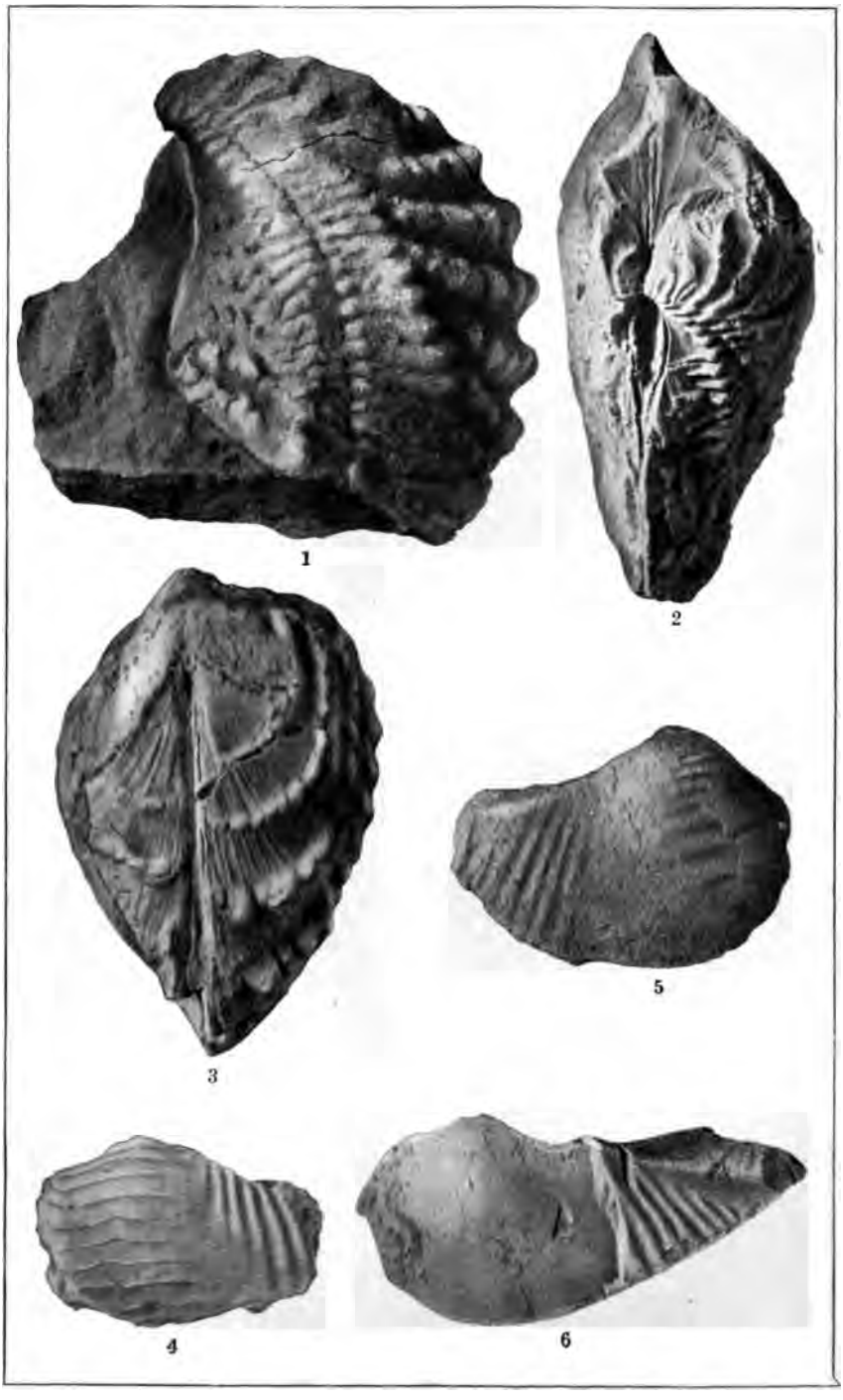


PLATE IX.

FIGS. 1–3. TRIGONIA VYSCHETZKII Cragin (p. 56).
See Pl. VIII, fig. 1, for side view of fig. 3.
FIGS. 4–5. TRIGONIA CALDERONI (Castillo and Aguilera) (p. 59).

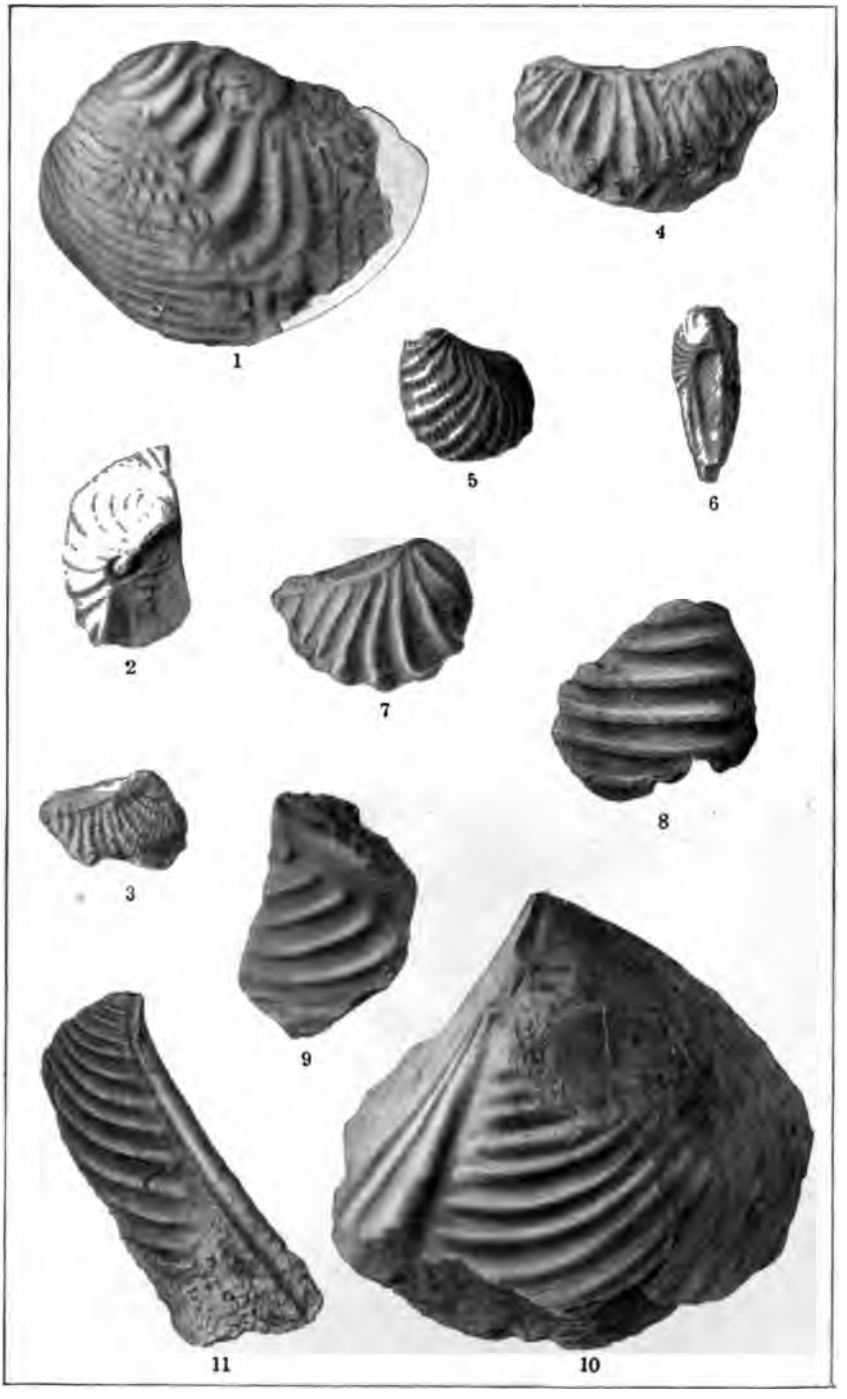


MALONE JURASSIC INVERTEBRATES.

PLATE X.

PLATE X.

FIGS. 1, 2. TRIGONIA GOODELLII Cragin (p. 58).
FIGS. 3–6. TRIGONIA PROSCABRA sp. n. (p. 60).
FIG. 7. TRIGONIA PRÆSTRIATA sp. n. (p. 61).
FIGS. 8–11. TRIGONIA MUNITA sp. n. (p. 62).



MALONE JURASSIC INVERTEBRATES.

PLATE XI.

PLATE XI.

FIGS. 1, 2. TRIGONIA RUDICOSTATA sp. n. (p. 63).
Side and profile views of the type specimen.

FIG. 3. TRIGONIA CONFERTICOSTATA sp. n. (p. 63).

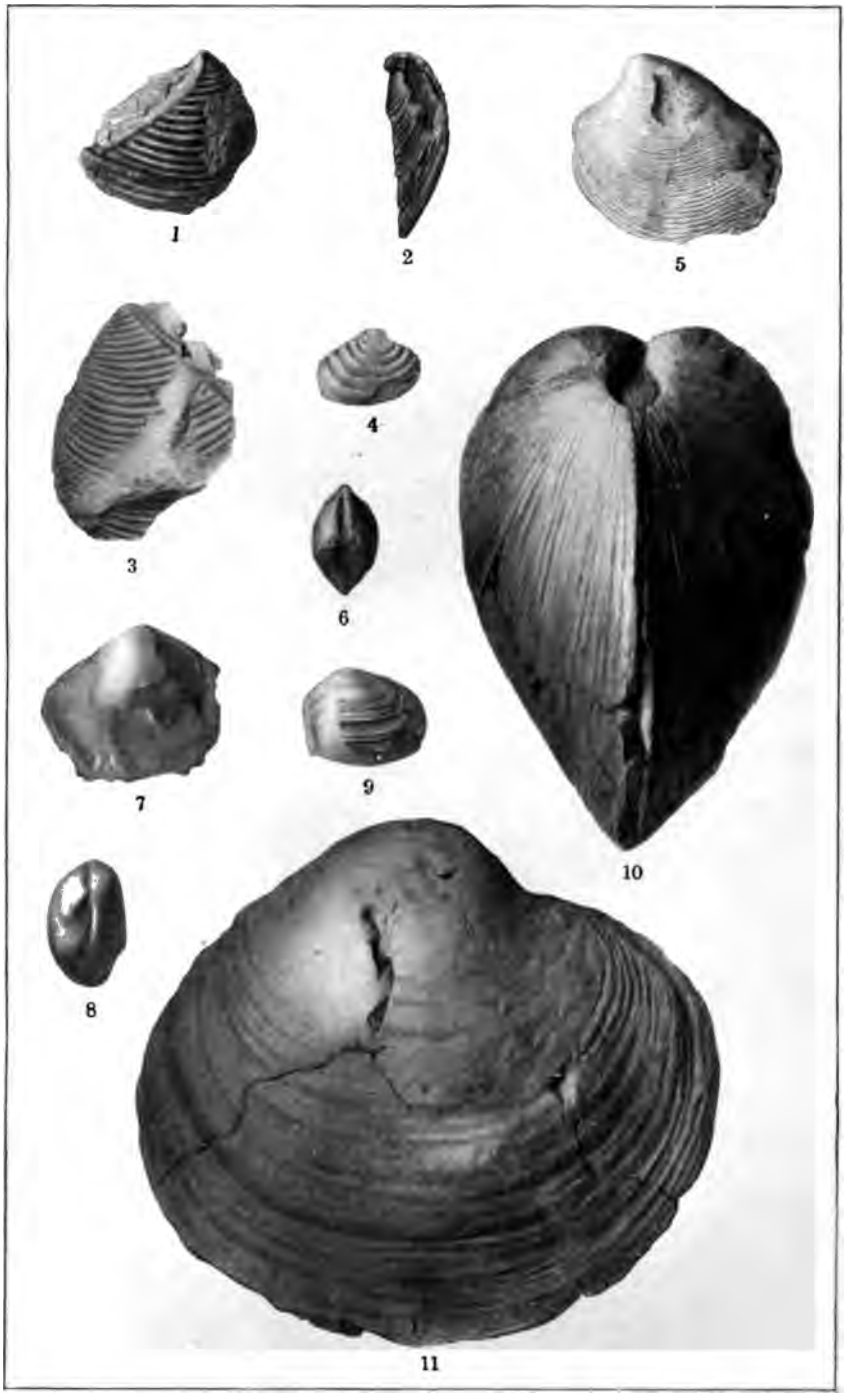
FIG. 4. ASTARTE BREVIACOLA sp. n. (p. 64).

FIGS. 5, 6. ASTARTE POSTICALVA sp. n. (p. 67).
Fig. 5. Left valve of type enlarged 2 diameters.
Fig. 6. Dorsal view of another specimen.

FIG. 7. ASTARTE CRATICULA sp. n. (p. 68).

FIGS. 8, 9. ASTARTE? ISODONTOIDES sp. n. (p. 67).

FIGS. 10, 11. ASTARTE MAIONENSIS Cragin (p. 65),
See Pl. XII for additional figures.

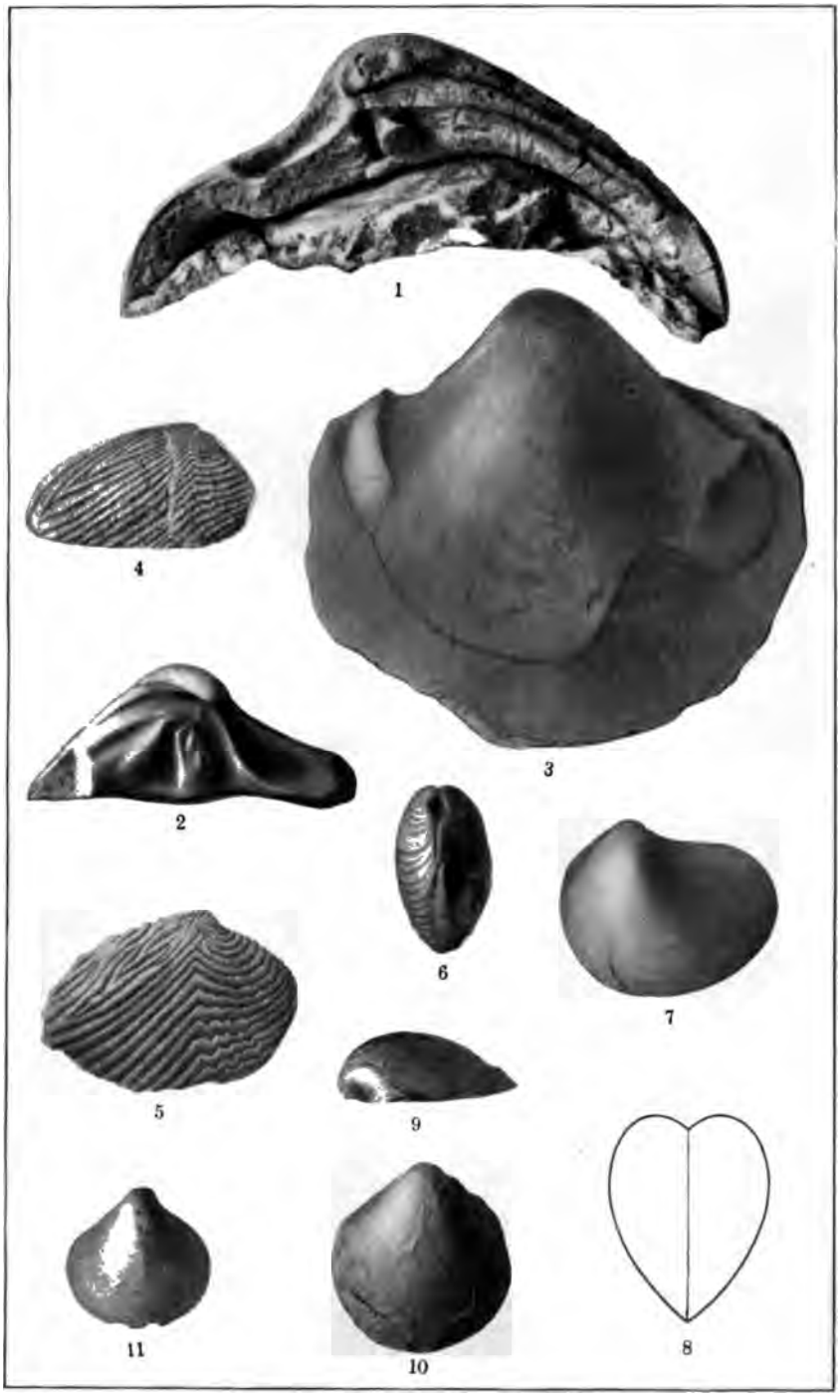


MALONE JURASSIC INVERTEBRATES.

PLATE XII.

PLATE XII.

FIGS. 1–3. ASTARTE MALONENSIS Cragin (p. 65).
See Pl. XI for additional figures.
FIGS. 4–6. PTYCHOMYA STANTONI sp. n. (p. 69).
Fig. 4. Natural size.
Figs. 5, 6. Another specimen enlarged 1½ diameters.
FIGS. 7, 8. UNICARDIUM ? TRANSVERSUM sp. n. (p. 76).
FIGS. 9–11. UNICARDIUM ? SEMIROTUNDUM sp. n. (p. 76).

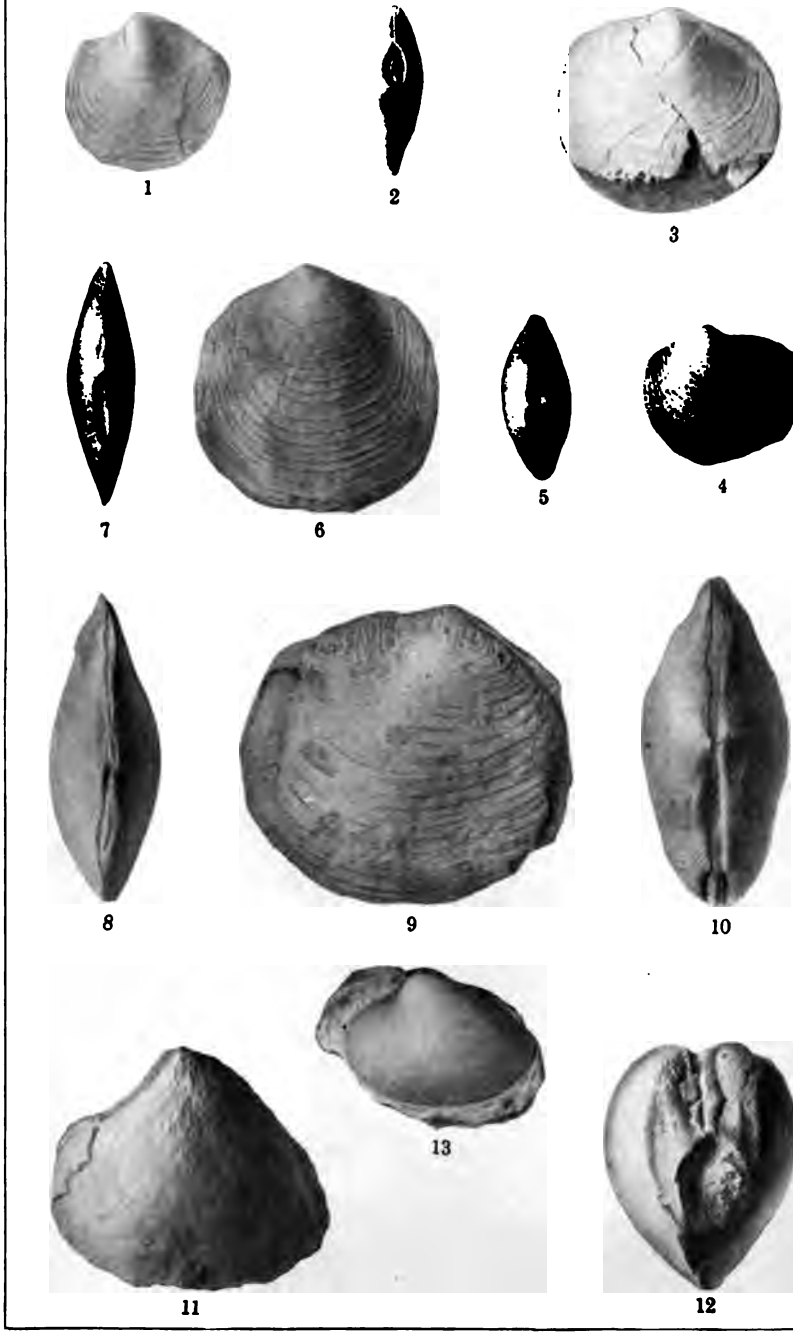


MALONE JURASSIC INVERTEBRATES.

PLATE XIII.

PLATE XIII.

FIGS. 1, 2. CYPRINA STREERUVITZII Cragin (p 78).
FIG. 3. LUCINA PLANIUSCULA sp. n. (p. 75).
FIGS. 4, 5. LUCINA POTOSINA Castillo and Aguilera (p. 72).
FIGS. 6–10. LUCINA POTOSINA var. metrica var. n. (p. 73).
FIGS. 11, 12. CYPRINA COTEROI Castillo and Aguilera (p. 77).
FIG. 13. TAPES CUNEOVATUS sp. n. (p. 79).



MALONE JURASSIC INVERTEBRATES.

PLATE XIV.

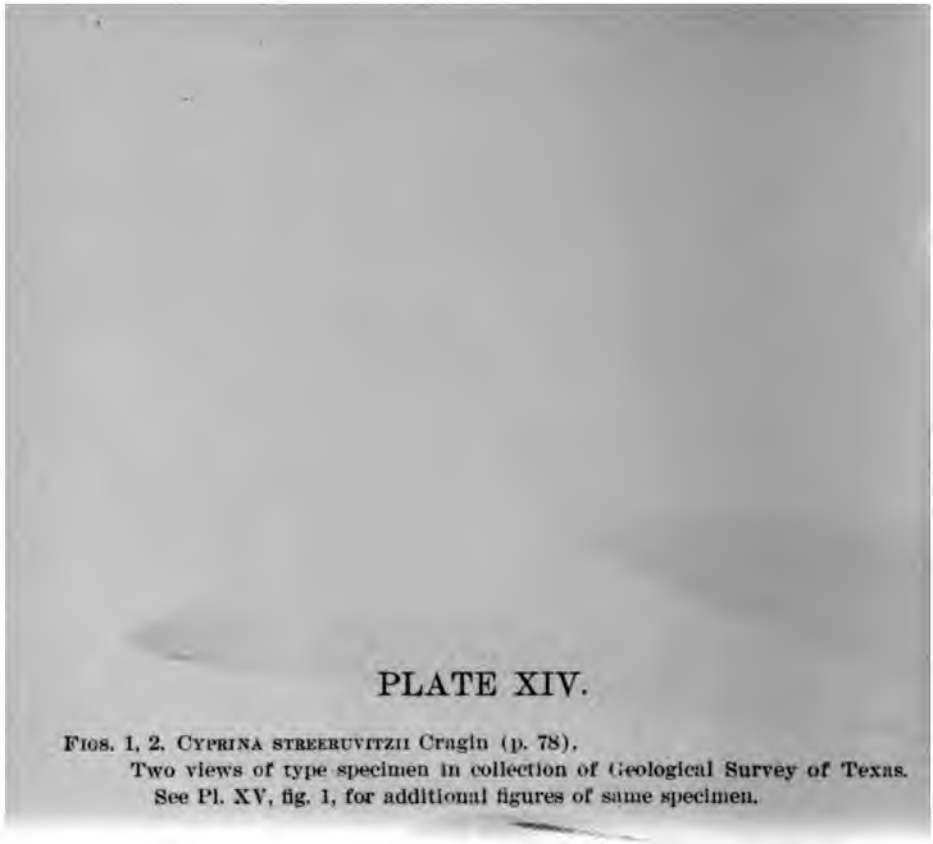


PLATE XIV.

FIGS. 1, 2. CYPRINA STREERUVITZII Cragin (p. 78).
Two views of type specimen in collection of Geological Survey of Texas.
See Pl. XV, fig. 1, for additional figures of same specimen.

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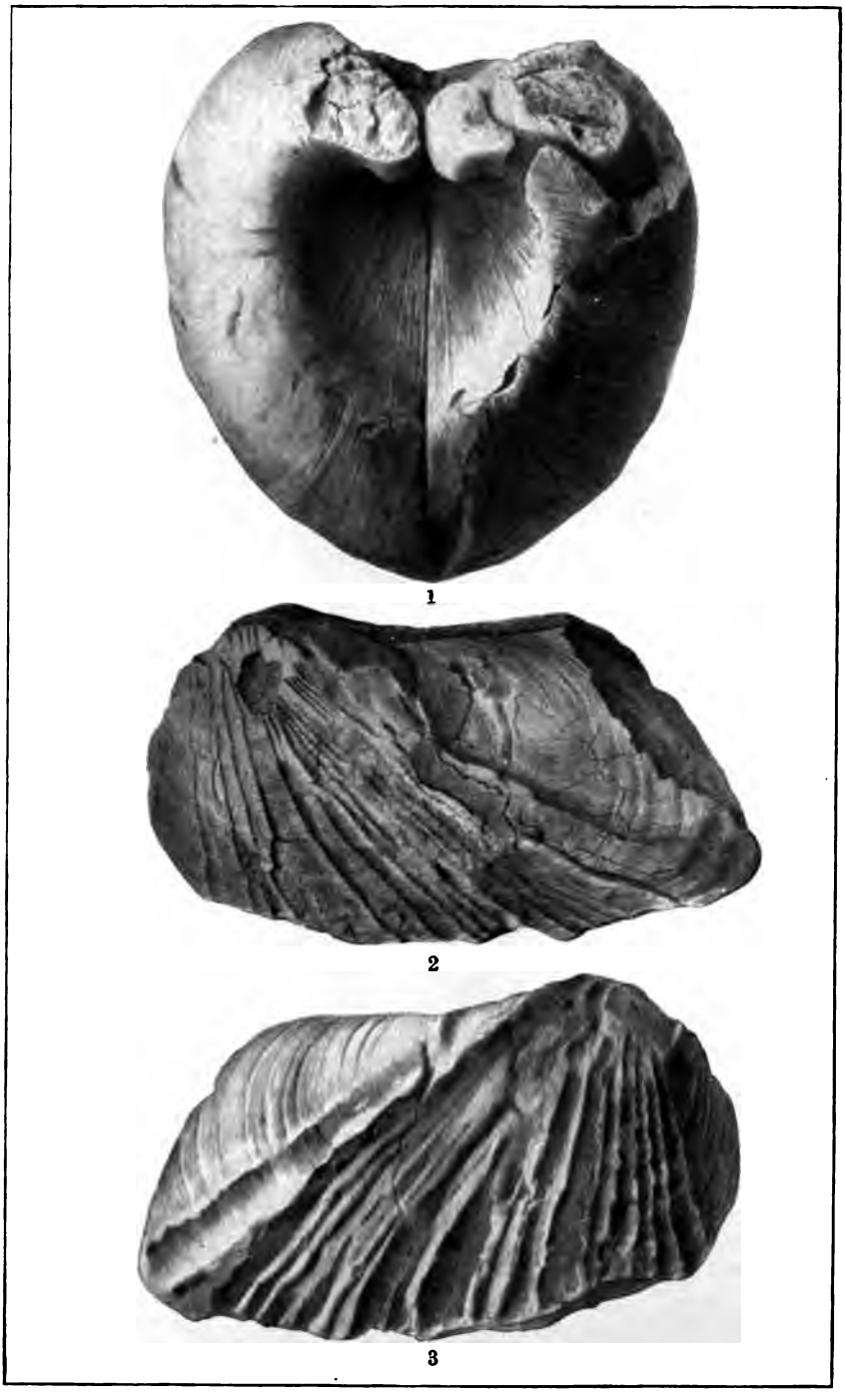
MALONE JURASSIC INVERTEBRATES.

PLATE XV.

PLATE XV.

FIG. 1. CYPRINA ? STREERUVITZII Cragin (p. 78).
See Pl. XIV for other views of same specimen.

FIGS. 2, 3. PHOLADOMYA TOSTA sp. n. (p. 79).
Opposite views of the same specimen.



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MALONE JURASSIC INVERTEBRATES.

PLATE XVI.

PLATE XVI.

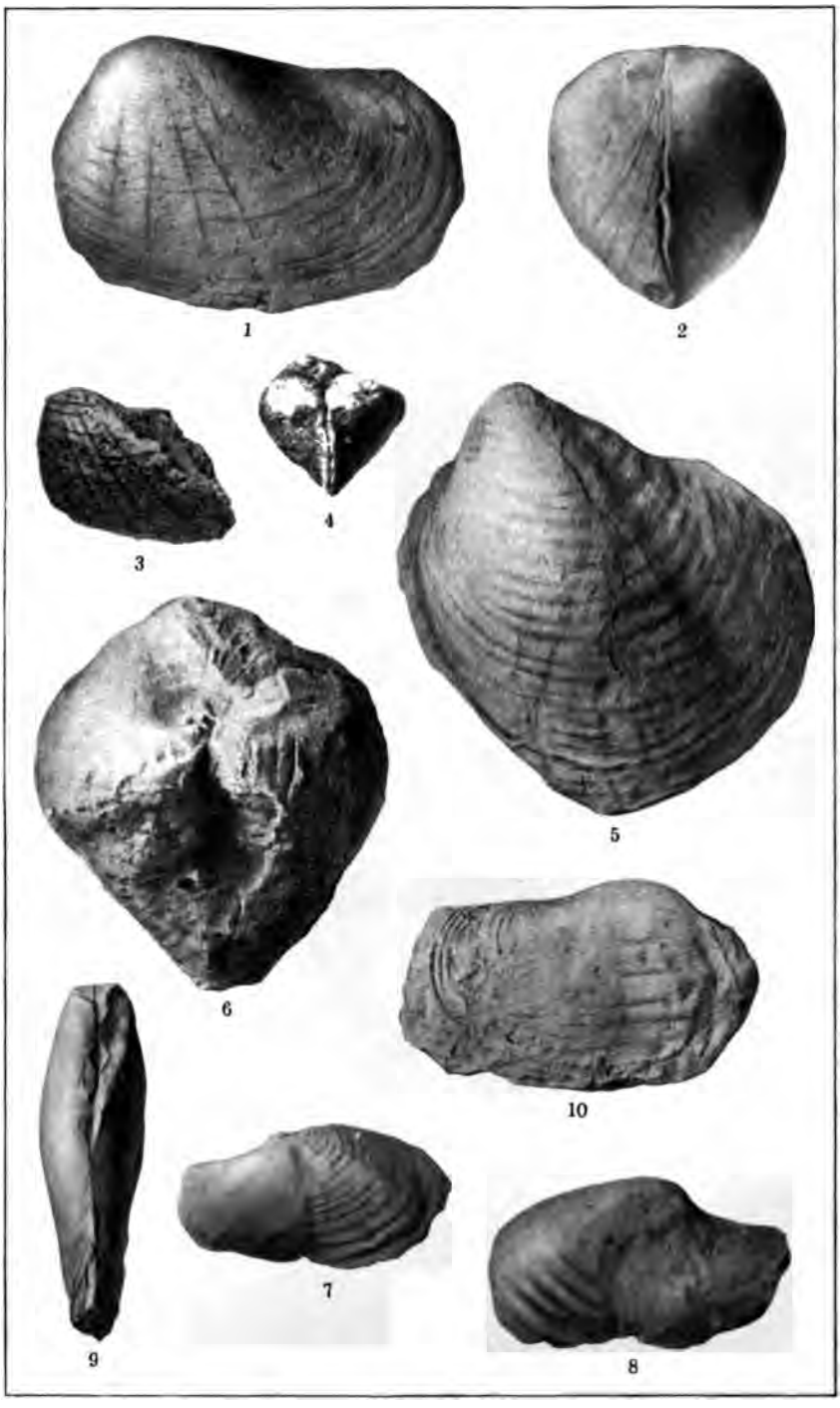
FIGS. 1, 2. PHOLADOMYA MARCOUI sp. n. (p. 80).
Side and anterior views of the same specimen.

FIGS. 3, 4. PHOLADOMYA PRÆPOSITA sp. n. (p. 82).
Two views of the same specimen.

FIGS. 5, 6. PHOLADOMYA PAUCICOSTA Roemer? (p. 81).
Side and dorsal views of the same specimen.

FIGS. 7, 8. ANATINA OBLIQUIPLICATA sp. n. (p. 85).

FIGS. 9, 10. ANATINA ? PLICULIFERA sp. n. (p. 86).

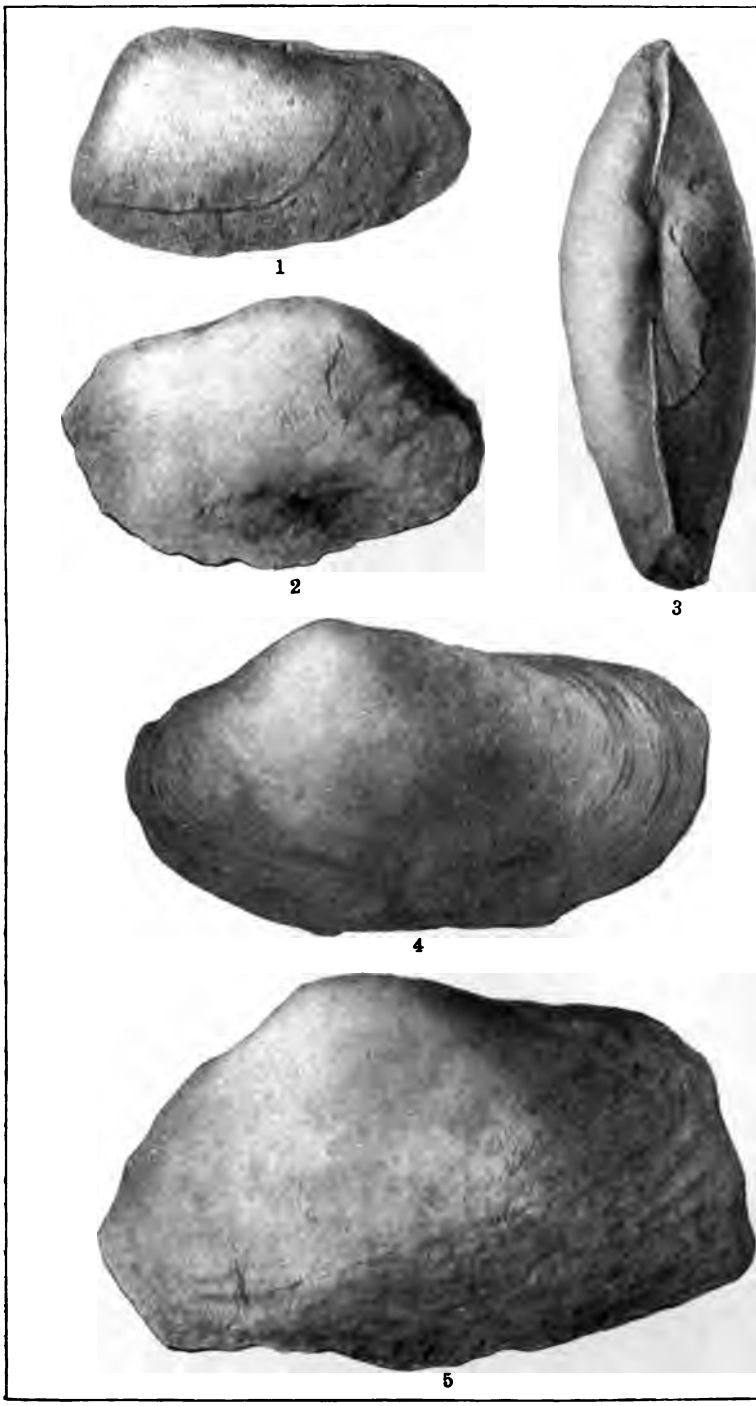


MALONE JURASSIC INVERTEBRATES.

PLATE XVII.

PLATE XVII.

FIGS. 1–5. PLEUROMYA INCONSTANS Castillo and Aguilera (p. 82).
See Pl. XVIII for additional figures.



MALONE JURASSIC INVERTEBRATES.

PLATE XVIII.

PLATE XVIII.

FIGS. 1–3. PLEUROMYA INCONSTANS Castillo and Aguilera (p. 82).
See Pl. XVII for additional figures.

FIG. 4. PLEUROMYA INCONSTANS var. curta var. n. (p. 84).
See Pl. XIX for additional figures.

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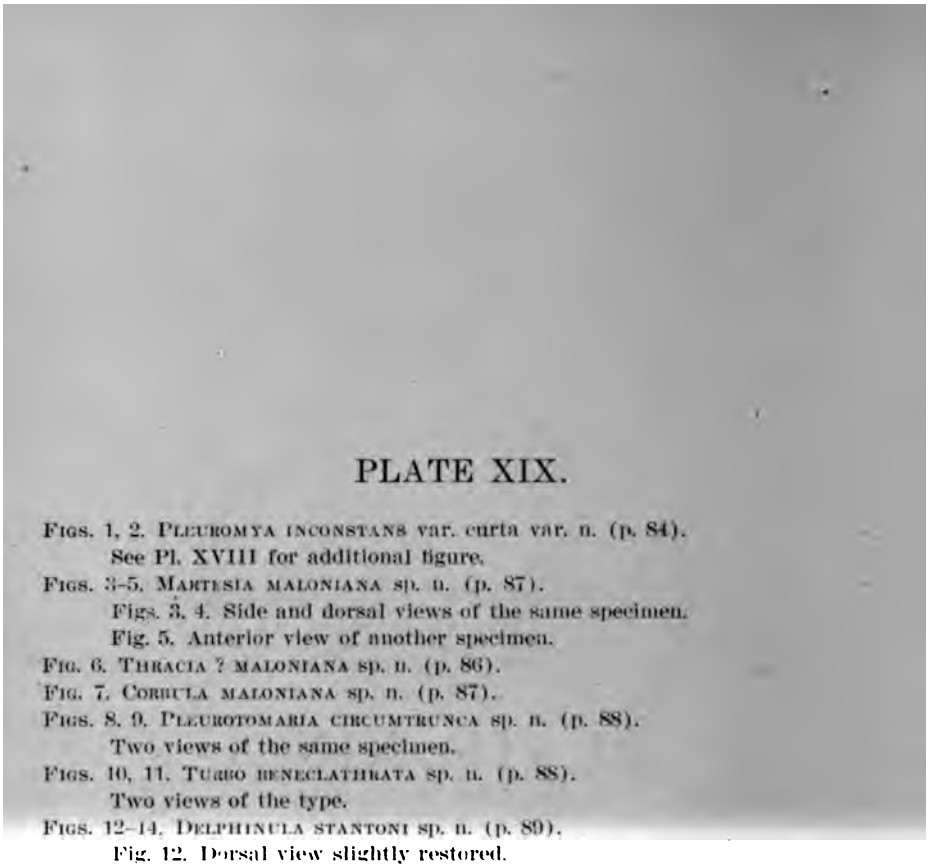
MALONE JURASSIC INVERTEBRATES.

PLATE XIX.

PLATE XIX.



FIGS. 1, 2. PLEUROMYA INCONSTANS var. curta var. n. (p. 84).
See Pl. XVIII for additional figure.

FIGS. 3–5. MARTESIA MALONIANA sp. n. (p. 87).
Figs. 3, 4. Side and dorsal views of the same specimen.
Fig. 5. Anterior view of another specimen.

FIG. 6. THRACIA ? MALONIANA sp. n. (p. 86).

FIG. 7. CORBULA MALONIANA sp. n. (p. 87).

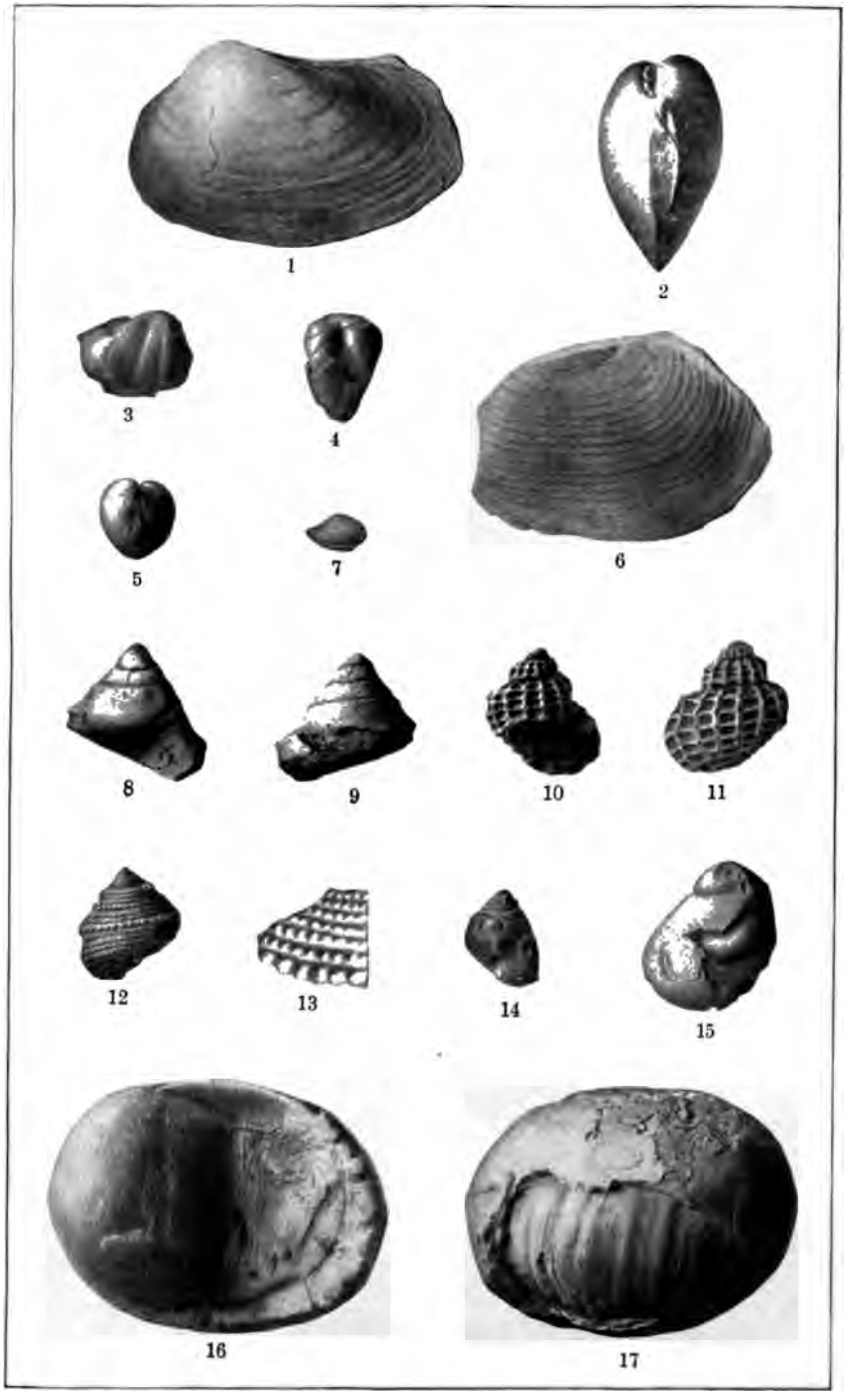
FIGS. 8, 9. PLEUROTOMARIA CIRCUMTRUNCA sp. n. (p. 88).
Two views of the same specimen.

FIGS. 10, 11. TURBO BENECLATHRATA sp. n. (p. 88).
Two views of the type.

FIGS. 12–14. DELPHINULA STANTONI sp. n. (p. 89).
Fig. 12. Dorsal view slightly restored.
Fig. 13. Enlargement of part of surface sculpture of same specimen.
Fig. 14. Aperture view of a small weathered specimen.

FIG. 15. NERITA FINLAYENSIS sp. n. (p. 90).

FIGS. 16, 17. NERITA PEROBLATA sp. n. (p. 91).
Two views of the type.

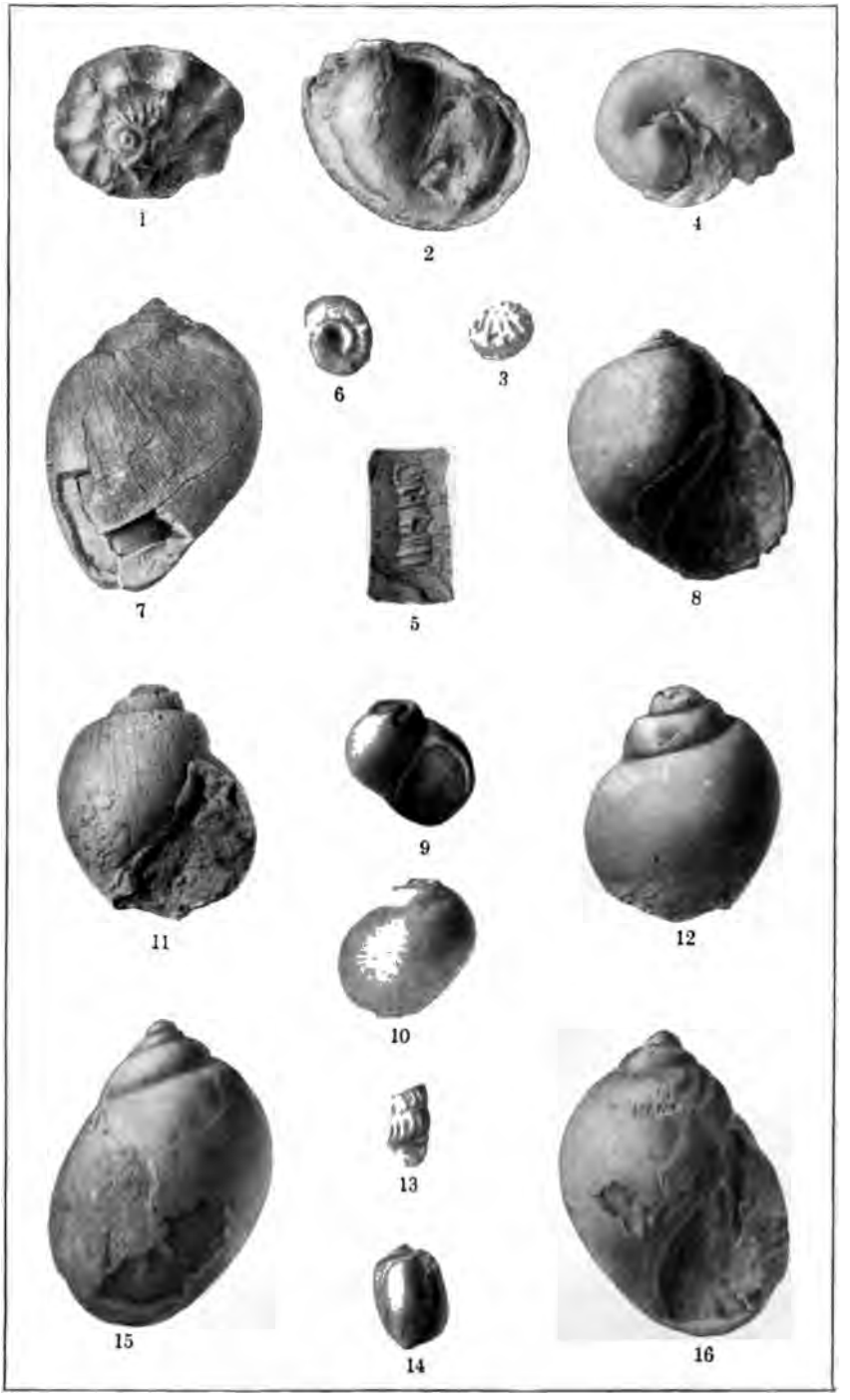


MALONE JURASSIC INVERTEBRATES.

PLATE XX.

PLATE XX.

FIGS. 1–4. NERITA NODILIRATA sp. n. (p. 90).
Fig. 1. Apical view of a medium specimen.
Fig. 2. Aperture view of another specimen viewed obliquely from the base so that the spire is concealed.
Fig. 3. Dorsal view of a young individual.
Fig. 4. Apical view of an internal cast.
FIG. 5. TURRITELLA BURKARTI sp. n. (p. 92).
FIG. 6. VERMETUS CORNEJOI Castillo and Aguilera (p. 92).
FIGS. 7, 8. NATICA WILLIAMSI sp. n. (p. 93).
FIGS. 9, 10. NATICA BILABIATA sp. n. (p. 95).
FIGS. 11, 12. NATICA INFLECTA sp. n. (p. 94).
FIG. 13. CERITHIUM ARCUIFERUM sp. n. (p. 99).
FIG. 14. ACTÆONINA ? MALONIANA sp. n. (p. 99).
FIGS. 15, 16. NATICA FINLAYENSIS sp. n. (p. 94).



MALONE JURASSIC INVERTEBRATES.

PLATE XXI.

PLATE XXI.

FIGS. 1–3. NERINEA GOODELLII sp. n. (p. 96).

FIGS. 4, 5. NERINEA CIRCUMVOLUTA sp. n. (p. 97).

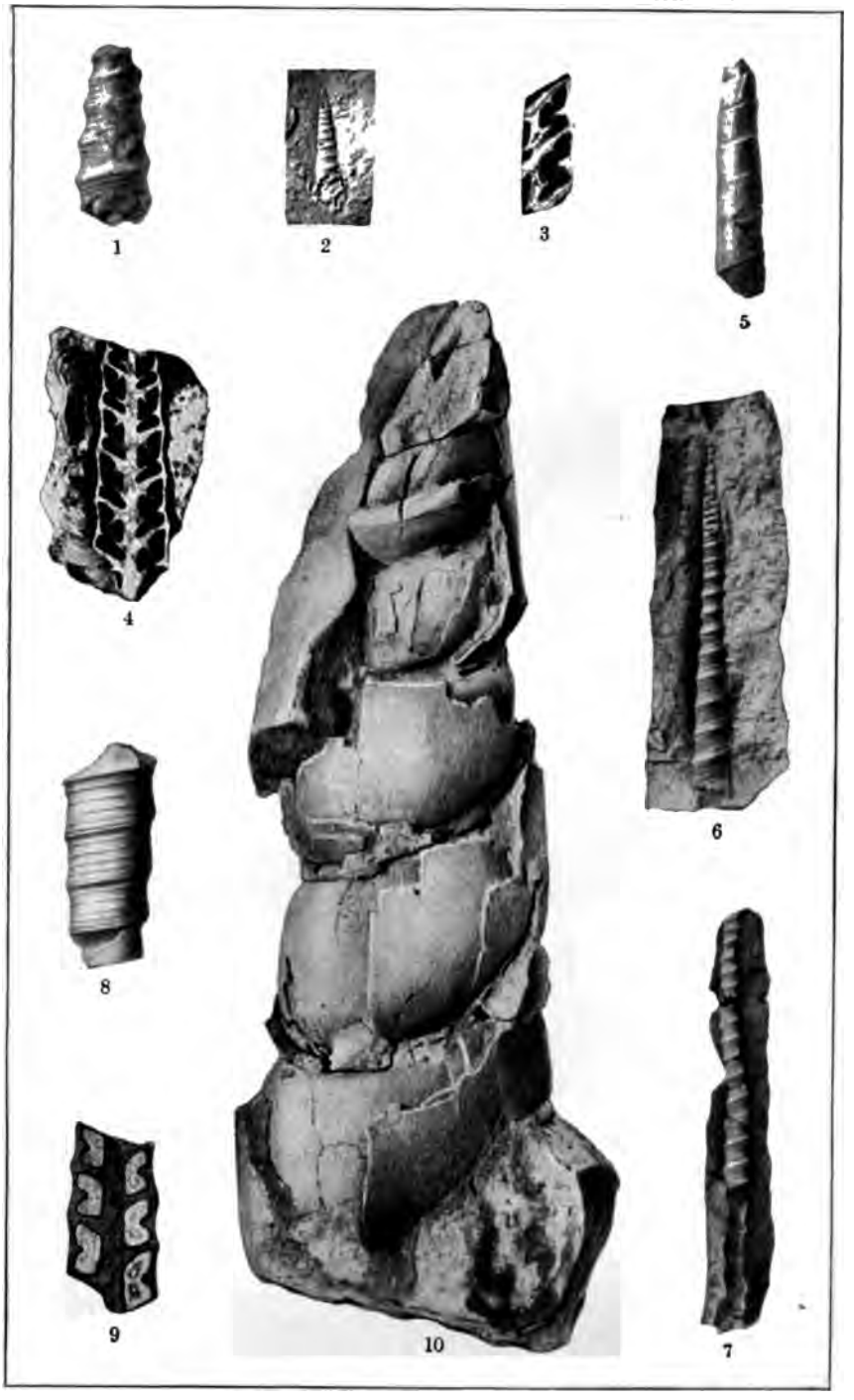
Fig. 4. Longitudinal section enlarged 2 diameters.

FIGS. 6–9. NERINELLA STANTONI sp. n. (p. 98).

Fig. 8. Fragment enlarged 3 diameters.

Fig. 9. Longitudinal section of same fragment enlarged.

FIG. 10. PSEUDOMELANIA GOODELLII sp. n. (p. 95).



MALONE JURASSIC INVERTEBRATES.

PLATE XXII.

PLATE XXII.

FIG. 1. NAUTILUS BURKARTI Castillo and Aguilera (p. 100).
FIGS. 2, 3. OPPELIA ? FALLAX Castillo and Aguilera (p. 101).

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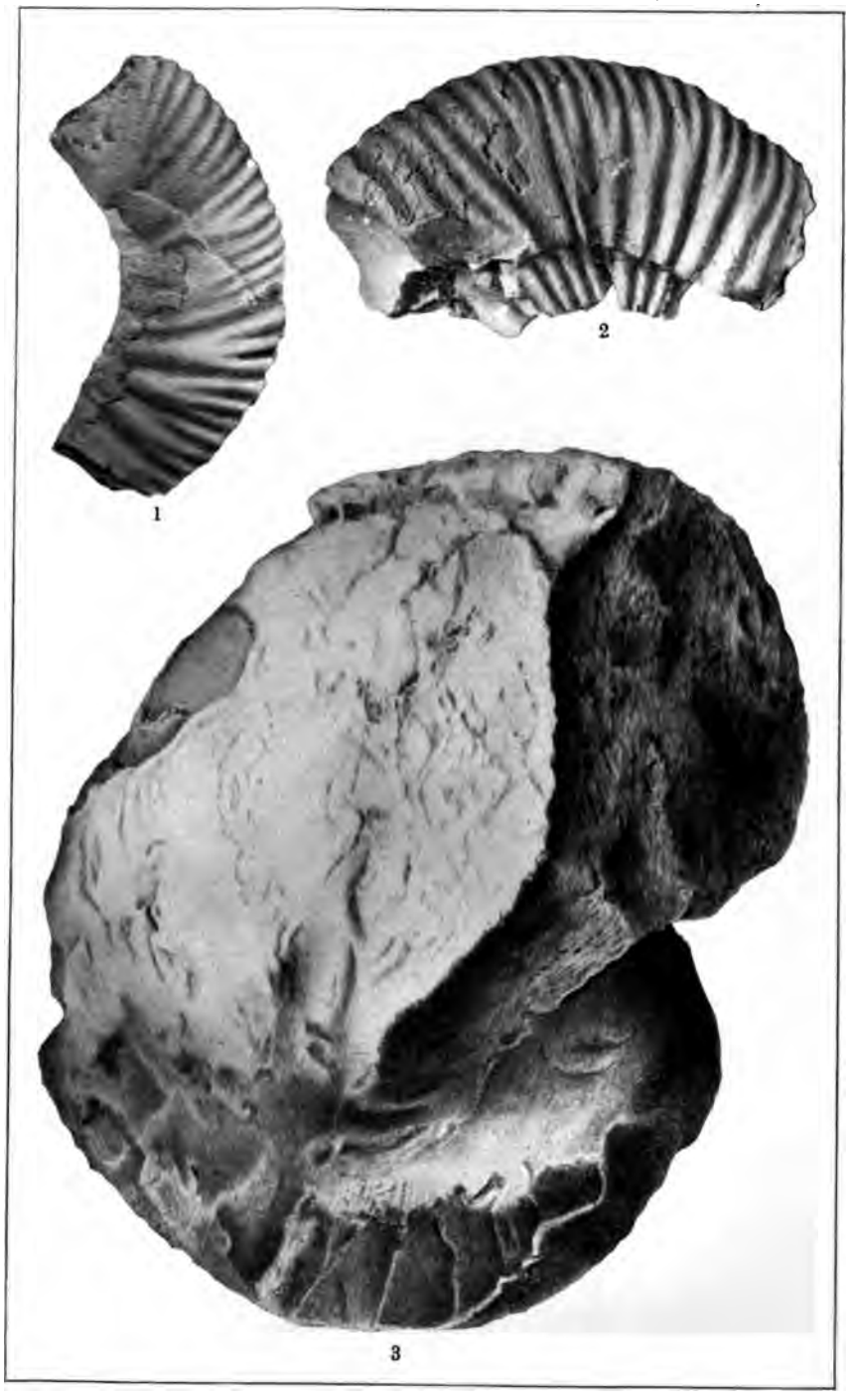
MALONE JURASSIC INVERTEBRATES.

PLATE XXIII.

PLATE XXIII.

FIG. 1. PERISPHINCTES POTOSINUS Castillo and Aguilera (p. 105).
FIG. 2. PERISPHINCTES FELIXI Castillo and Aguilera (p. 106).
FIG. 3. NAUTILUS NAUFRAGUS sp. n. (p. 100).
See Pl. XXIV, fig. 3.



MALONE JURASSIC INVERTEBRATES.

PLATE XXIV.

PLATE XXIV.

FIGS. 1, 2. OLCOSTEPHANUS MALONIANUS sp. n. (p. 103).
Lateral and ventral views of two fragments.

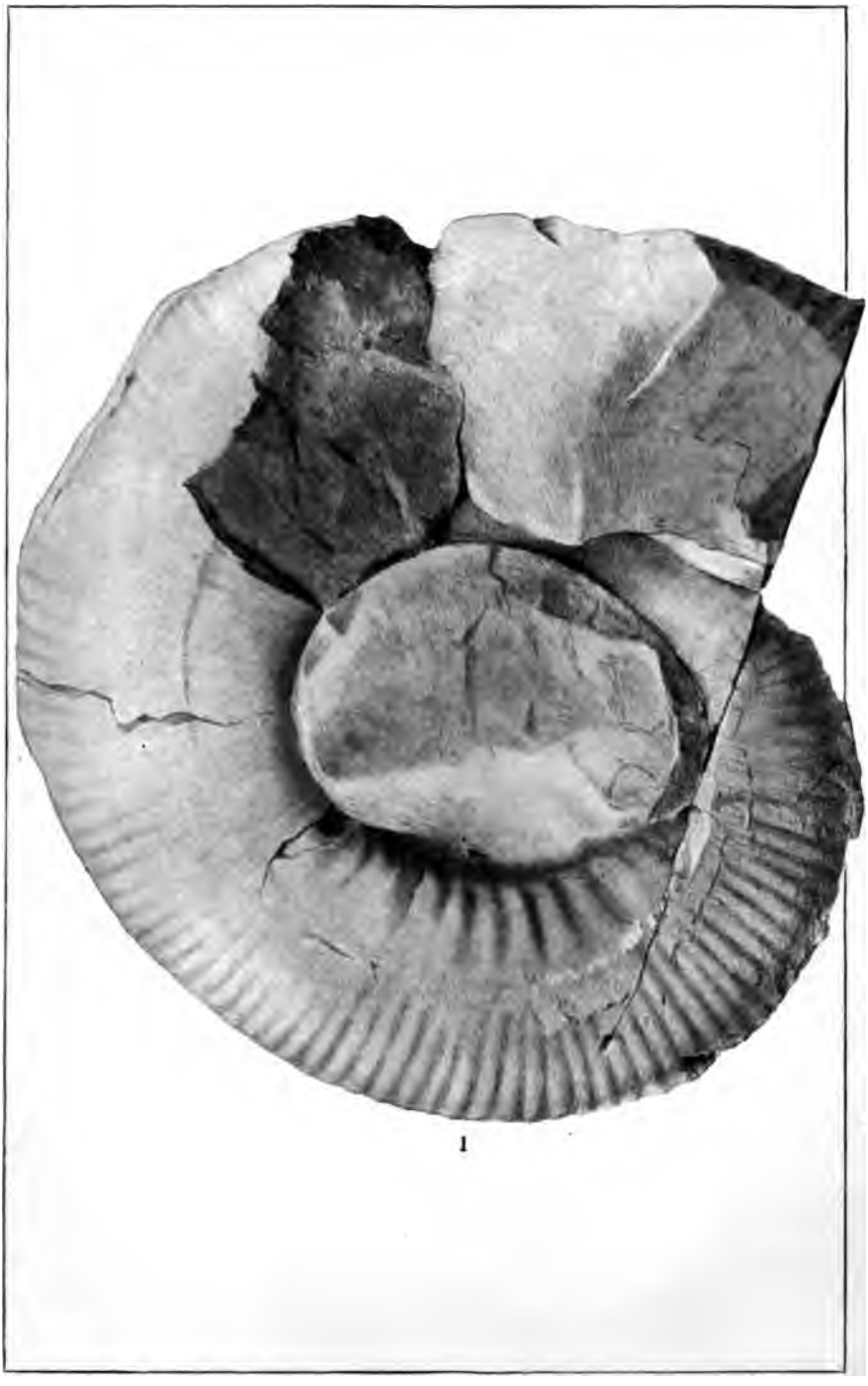
FIG. 3. NAUTILUS NAUFRAGUS sp. n. (p. 100).
Ventral view of specimen represented by Pl. XXIII, fig. 3.

MALONE JURASSIC INVERTEBRATES.

PLATE XXV.

PLATE XXV.

FIG. 1. PERISPHINCTES SCHUCHERTI sp. n. (p. 107).
See Pls. XXVI and XXVII for additional figures.



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MALONE JURASSIC INVERTEBRATES.

PLATE XXVI.

PLATE XXVI

FIGS. 1–3. PERISPHINCTES SCHUCHERTI sp. n. (p. 107).

Fig. 1. Ventral view of specimen figured on Pl. XXV.

Fig. 2. Side view of smaller specimen.

Fig. 3. Part of suture showing first and second lateral lobes from another specimen enlarged 3 diameters.

See Pl. XXVII for additional figure.

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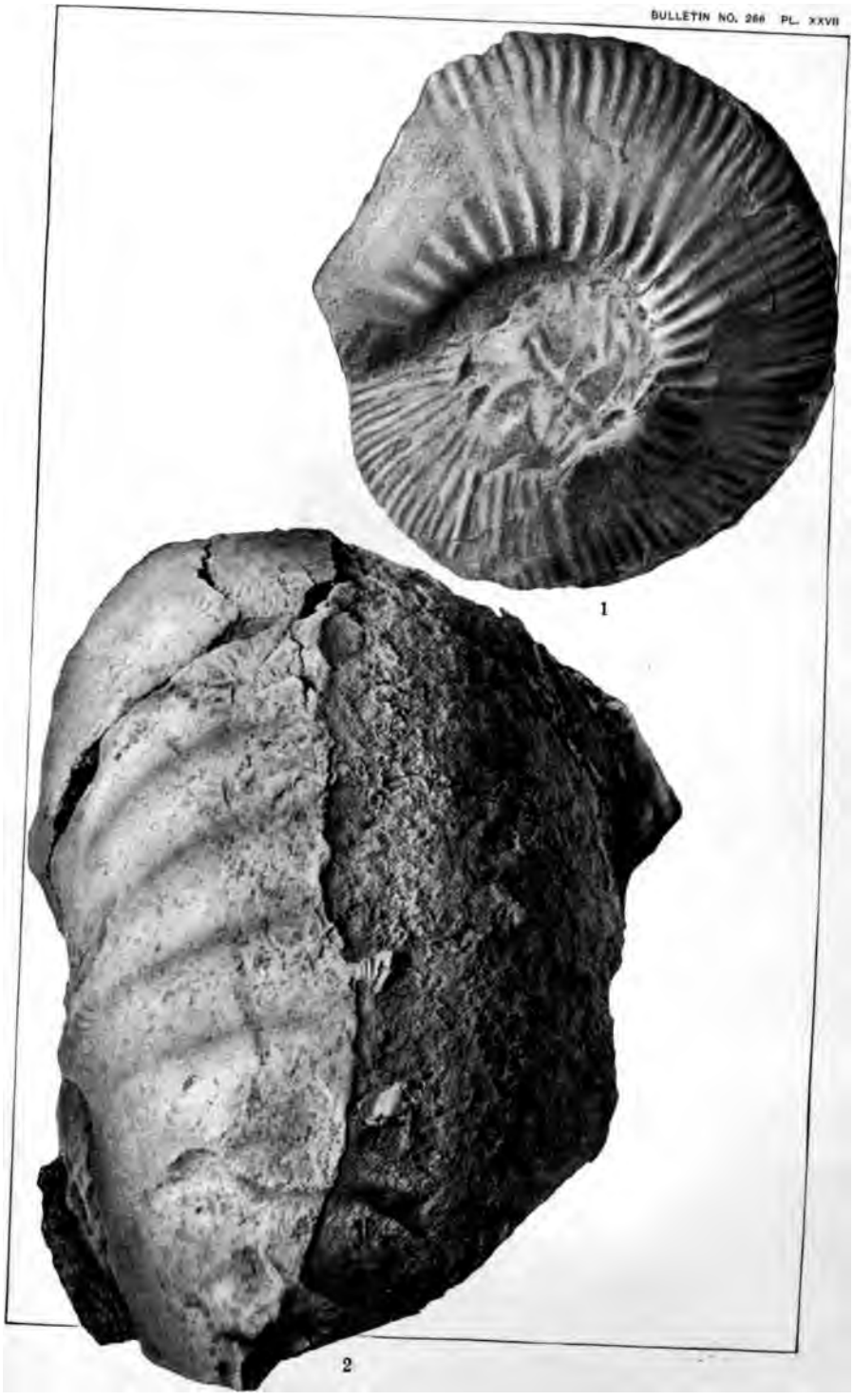
MALONE JURASSIC INVERTEBRATES.

PLATE XXVII.

PLATE XXVII.

FIG. 1. PERISPHINCTES SCHUCHERTI sp. n. (p. 107).
See Pls. XXV and XXVI for additional figures.

FIG. 2. ASPIDOCERAS ALAMITOCENSIS Castillo and Aguilera (p 109).
Ventral view of a fragment.



MALONE JURASSIC INVERTEBRATES.

PLATE XXVIII.

PLATE XXVIII.

FIGS. 1, 2. PERISPHINCTES AGUILERAI sp. n. (p. 105).

1

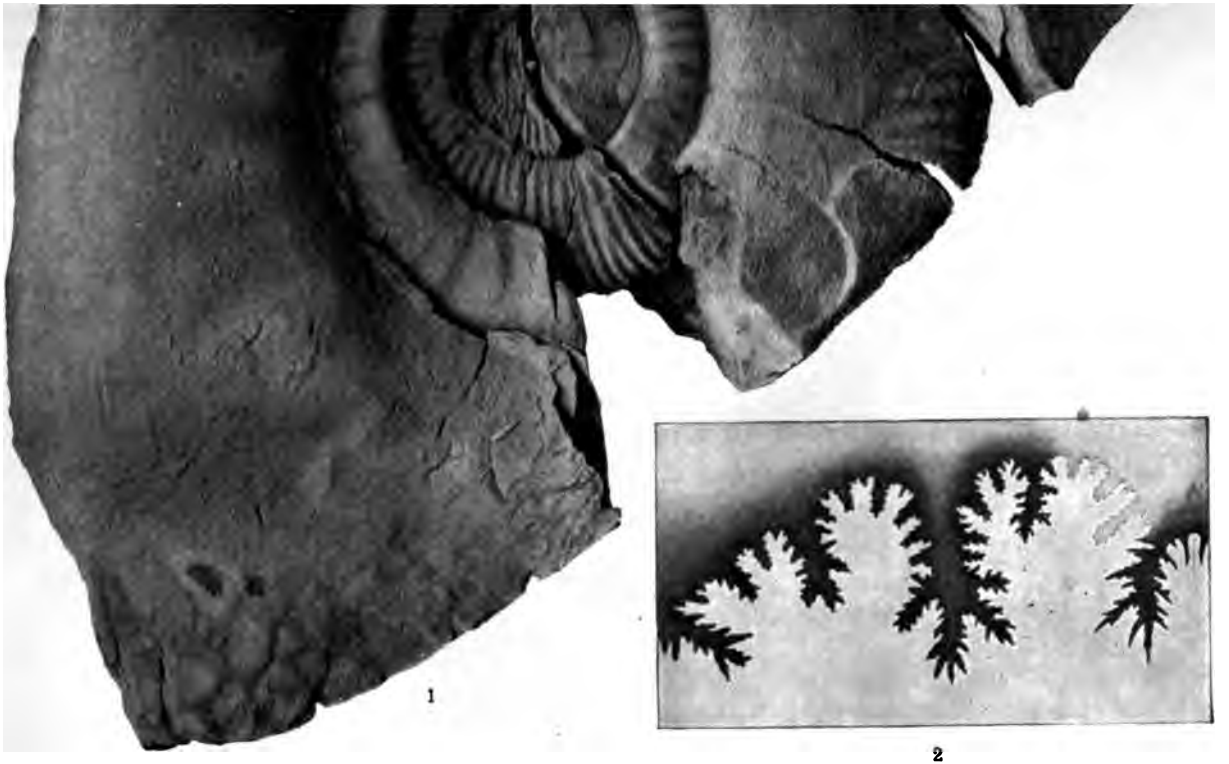
2

MALONE JURASSIC INVERTEBRATES.

PLATE XXIX.

PLATE XXIX.

FIGS. 1, 2. PERISPHINCTES CLARKI sp. n. (p. 103).
Fig. 1. A large imperfect specimen.
Fig. 2. Septum of same, somewhat weathered.



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MALONE JURASSIC INVERTEBRATES.

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[Names in italic are synonyms; figures in black-face type denote pages on which species are described; figures in italic refer to illustrations.]

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THE

COPPER DEPOSITS OF MISSOURI

BY

H. FOSTER BAIN AND E. O. ULRICH

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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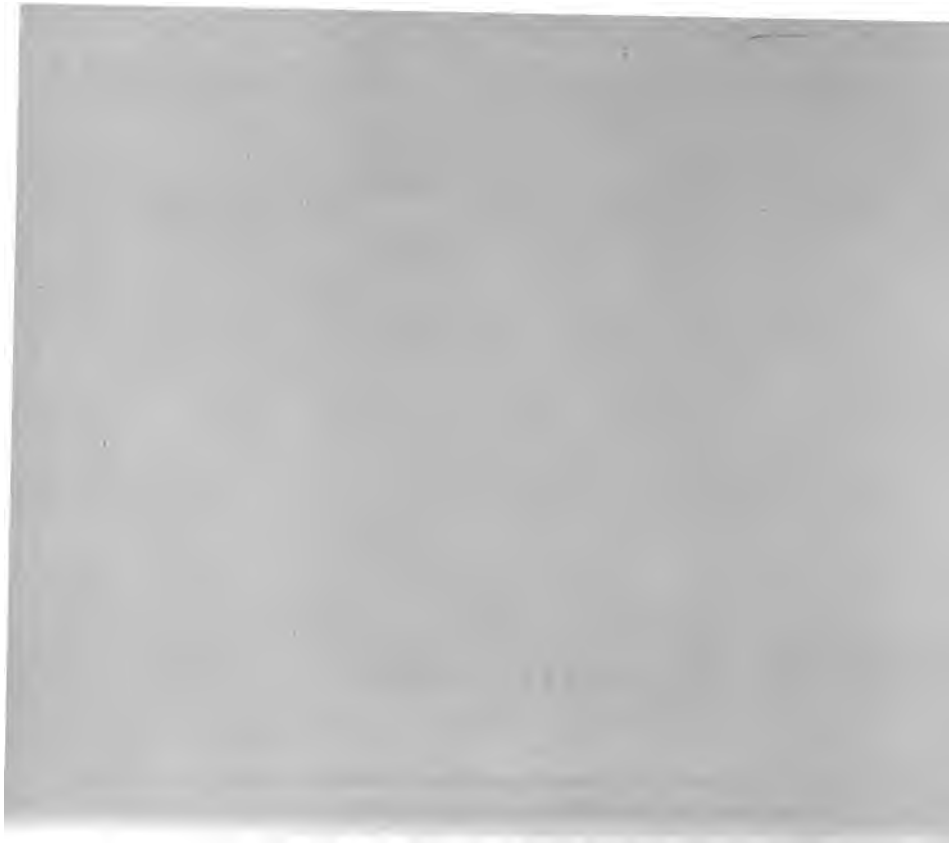

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., February 17, 1905.

SIR: I submit herewith the manuscript of a report on the copper deposits of Missouri, by H. Foster Bain and E. O. Ulrich, and recommend its publication as a bulletin.

The report is the result of field work undertaken last season by Messrs. Bain and Ulrich in response to numerous requests for information concerning the copper deposits of Missouri. It contains a summary of all available information regarding the copper deposits and a preliminary statement of the stratigraphy of the region in as great detail as the facts at hand warrant and as is necessary to a proper understanding of the occurrence and geological relations of the copper.

Very respectfully,

C. W. HAYES,
Geologist in Charge of Geology.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

COPPER DEPOSITS OF MISSOURI.

By H. Foster Bain and E. O. Ulrich.

INTRODUCTION.

Scope of this report.—Copper is now being mined and smelted near Sullivan, Mo., and at other points in the State copper deposits are attracting attention. The present paper is a brief account of those deposits which have so far been mined, with such suggestions as seem warranted regarding further prospecting. The occurrence of copper in quantities permitting actual exploitation in the midst of a great area of unaltered and little disturbed sedimentary rocks raises many interesting questions of genesis. These, however, can not be adequately discussed until the general studies upon the lead, zinc, and other ores of the Mississippi Valley are somewhat further advanced.

The present paper is based upon work done in 1904 by the authors, assisted by E. E. Ellis. Mr. Bain is responsible for all statements relating to the ore deposits and mines, while Mr. Ulrich has made the determinations of the geologic horizons and has written the description of the formations.

History.—Attempts to mine copper have been made in Missouri since 1837, and at different times copper furnaces have been operated in Shannon, Ste. Genevieve, and Crawford counties, while a matte carrying in addition nickel and cobalt has been steadily produced at Mine La Motte. These localities are shown on the accompanying sketch map (fig. 1, p. 11). Copper has probably been shipped in small quantities from several other counties also. Shumard,[a] writing in 1860, enumerated 15 counties in which copper was known to occur. Even at that he missed Ste. Genevieve, the one from which the main output has come. Very little attempt had then been made to develop the deposits. After the work of Joseph Slater in Shannon County in 1837 no serious effort to mine was made until 1876, when Charles T. Biser shipped a few carloads from the same locality. About the same time the Ste. Genevieve mines were developed, and they continued in operation until about six years ago. In 1904 the furnace of

[a] Shumard, B. F., Report of progress: Missouri Geol. Survey, 1861, pp. 7–9.

the Missouri Copper Mountain Mining Company, at Sullivan, was put in blast and metal began to be shipped to Chicago for refining.

There are no exact figures of the amount of copper so far produced. Ladd[a] estimated the total as having been worth less than $20,000. This is probably too low, since the Ste. Genevieve mines produced regularly for some years and in 1880 alone were credited by the Tenth Census with an output of $25,730. Local estimates of the production of the Slater mine, in Shannon County, indicated a production of approximately $50,000. In 1903 the State mine inspector, G. K. Williams, is quoted[b] as estimating the sales of copper ore for the year to amount to $30,210. In 1904 the furnace at Sullivan shipped two carloads of metal, and for some years a copper matte has been regularly shipped from Mine La Motte. From this it appears that copper in important amounts has been actually marketed from this State for some years.

General distribution of the copper.—Copper-bearing pyrites are widely distributed in Missouri, as in many other States, and the brilliant colors of the alteration products lead to ready recognition. Occurrences have been noted in Benton, Clark, Crawford, Dade, Dallas, Dent, Franklin, Greene, Iron, Jasper, Jefferson, Lawrence, Madison, Maries, St. Francois, Ste. Genevieve, Shannon, Washington, and probably a number of other counties. For the most part these occurrences may be at once dismissed as of no economic importance. The four which have yielded ore have already been noted.

With the exception of one or two sporadic occurrences of merely mineralogic interest, copper is found only in the southern part of Missouri, within the region broadly known as the Ozark uplift. This is an elliptical, warped plateau having a major northeast-southwest axis of some 300 miles and reaching its topographic culmination at Cedar Gap, somewhat west of the copper-bearing territory.

Its geologic center is to the east, where, in Iron, Madison, St. Francois, and adjacent counties, there exists a series of semidetached elevations made up of crystalline rocks, known as the "St. Francis Mountains." These rocks, mainly granite and porphyry, but with subordinate amounts of basic intrusives and probably of metamorphosed sediments, are of pre-Cambrian age. Around them in concentric belts, each wider to the west than the east, are the Cambrian, Ordovician, and later rocks, more especially described below. The region is one of important and varied mineral wealth. Iron, lead, zinc, barite, and manganese, as well as copper, occur and are mined. Despite the fact that it includes some of the earliest American settlements, considerable areas within it are very sparsely settled, are undeveloped, and, in comparison with the surrounding territory, are

[a] Ladd, G. E., Mining: The State of Missouri, by Walter Williams, 1904, p. 179.
[b] Eng. and Min. Jour., New York, vol. 76, 1903, p. 739.

inaccessible. It is not surprising, therefore, that promising mineral prospects have been, in some instances, inadequately investigated.

Copper occurs as far south and west as in the Joplin zinc district, where chalcopyrite is very common and many of the copper oxides, carbonates, etc., have been recognized. It is to be noted, however, that the areas in which it occurs so abundantly as to have induced efforts to mine it are all located near the core of crystalline rocks, a

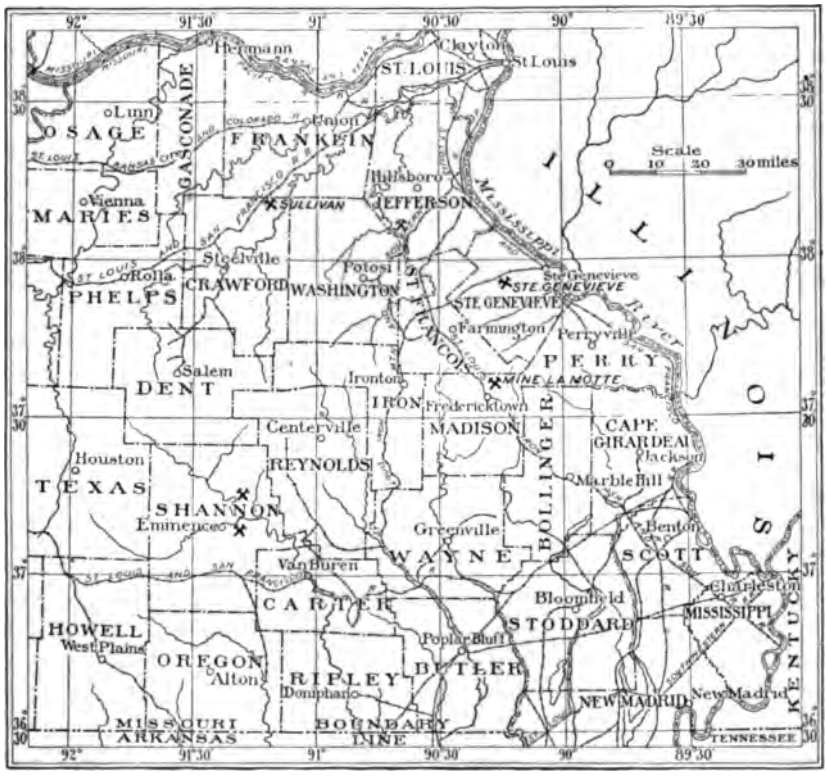

FIG. 1.—Sketch map showing location of copper deposits.

relation which becomes more striking as the individual occurrences are examined. The pre-Cambrian age of these rocks is well attested, and there is no evidence of any later igneous activity in the district. A possible exception is the occurrence of a dike of graphic granite in Camden County, which Professor Shepard has described.[a] Here an intrusion took place in post-Ordovician and probably post-Devonian time. It does not seem, however, to have been accompanied by important mineralization, and has no apparent connection with any copper deposit.

[a] Shepard, E. M., Spring system of the Decaturville dome, Camden County, Mo.: Water-Sup. and Irr. Paper No. 110, U. S. Geol. Survey, 1904, pp. 113–125.

Classification and synonymy of the formations of the "Magnesian" or "Ozark series" in Missouri.

System	Series.		Formation.	Thickness	Synonyms.
Ordovician.	Saratogan and Lower Ordovician.	Potosi or Yellville group.	Joachim limestone.	0–150	First Magnesian limestone. Folley limestone.[a]
			St. Peter ("Crystal City") sandstone.	0–200	First or Saccharoidal sandstone. Cap-au-Grès sandstone. Pacific sandstone. "Key sandstone" in Yellville district of Arkansas.
			Jefferson City limestone.	50–250	Second Magnesian limestone. Winfield limestone. Finley limestone.[b] ?Marshfield sandstone.
----?----			Roubidoux formation.	70–225+	Second sandstone. Moreau sandstone. St. Elizabeth formation and Bolin Creek sandstone member. ?Marshfield sandstone. ?Bolivar sandstone.
Cambrian.			Gasconade limestone.	450–650	Third and Fourth Magnesian limestones and Third sandstones. Includes Osage limestone. Cole Camp sandstone of Winslow; also Gasconade limestone, Gunter sandstone, and Proctor limestone of Ball and Smith. Lesueur limestone.
		True Saratogan.	Elvins formation	0–120	Basal part of the Potosi limestone and the "Potosi slates and conglomerates" of Nason.
	Acadian.		Bonneterre limestone.	----------	?Fourth Magnesian limestone (in part). Decaturville limestone.
			La Motte sandstone	0–300	Second sandstone of Shumard (in part).
			Archean granites and porphyries.		

[a] The names "Folley limestone," "Cap-au-Grès sandstone," and "Winfield limestone," together with a number of other new names, were published by Keyes in a paper entitled Some geological formations of the Cap-au-Grès uplift: Proc. Iowa Acad. Sci., vol. 5, 1898, pp. 58–63.

[b] The names "Finley limestone," "Marshfield sandstone," and "Decaturville limestone" appear in a provisional table of geologic formations in Missouri by Shepard, E. M., Bull. Brad. Geol. Field Sta., 1904, p. 42.

GEOLOGY.

FORMER CLASSIFICATIONS OF THE ROCKS.

The geologic formations containing the copper deposits of Missouri, described in this paper, all belong to that difficult and much-discussed series of rocks commonly known as the "Magnesian series" and more recently called the "Ozark series."[a] Many and diverse attempts at subdividing and classifying these rocks have been made in the last fifty years. None has proved wholly satisfactory, and some have merely increased the confusion.

It is obviously impracticable to discuss the numerous and important problems connected with the Ozark series of rocks except in the briefest manner at this time. Besides, as it is proposed to continue the investigation of the stratigraphic problems during the coming field season, it would be unwise to hamper the final conclusions by a preliminary publication of views necessarily based on incomplete field observations and office studies. Still, these investigations have been sufficiently extended to induce the belief that the results here presented will not be materially modified.

In order that the following résumé may be made as intelligible as possible, it has been thought well to precede it with a table giving (1) the successive thickness and provisional classification of the formations, (2) the names of the formations that after a careful study of the matter have seemed to accord best with the demands of the rules of nomenclature, especially the rule of priority, and (3) the principal synonyms of each name.

Swallow's scheme.—In 1855 Swallow and his assistants[b] published a scheme of classification of the rocks in which the subdivisions were based primarily upon the separation of the rock by beds of sandstone usually much thinner than the limestone. These sandstones were regarded as widespread and constant in position, and hence of high value in the correlation of the beds of more or less magnesian limestones between them. Fossils being rare, and generally in an unfavorable state of preservation when found, and the older geologists seeming to have had confidence in the persistence of the sandstone beds, the numbering of the beds from above downward promised to be a happy solution of the difficulties.

From the beginning, however, of the later surveys of the State of Missouri, under Winslow, Keyes, and Buckley, the inadequacy and

[a] Broadhead, G. C., Am. Geol., vol. 8, 1891, p. 33. The term "Ozark series" is frequently employed in the following pages in a quoted sense. In the final nomenclature of the rocks of Missouri there can be no place for the term as defined by Broadhead. In the meantime, however, it is a convenient alternative for "Magnesian series."

[b] Swallow, G. C., First and Second Ann. Repts. Missouri Geol. Survey, 1855, pp. 114–131.

imperfections of Swallow's classification became more and more apparent. The impracticability of the prevailing mode of subdivision soon became obvious. They found not only more sandstones than were accounted for in Swallow's scheme, but also that most of these beds were mere lenses, appearing and disappearing with disconcerting frequency and irregularity.

Nason's work.—Nason,[a] in 1892, was the first to indicate these facts. However, in the course of his work on the rocks of the Ozark series he found that the general horizon that had been more constantly identified correctly than any of the other beds by Swallow and his assistants, and called the "Second sandstone," was really a persistent formation over a large part of the Ozark uplift. The name Roubidoux sandstone therefore was proposed by him as a geographic designation to take the place of Second sandstone. At the same time he proposed to call the formation beneath the Roubidoux the Gasconade limestone. Perhaps it is unfortunate that Nason failed to fix the lower limit of his Gasconade formation. From another view it is rather fortunate that he did not, since with the fuller knowledge of the entire section now available the want may be supplied in a manner more in accord with the best interests of stratigraphy than might have been possible in 1892.

Nason's supposition respecting the probable equivalence of the Roubidoux sandstone and Swallow's First or Saccharoidal sandstone as exhibited at Pacific and Crystal City (op. cit., p. 115) is unquestionably an error, and doubtless was occasioned by his justifiable loss of confidence in the ability of the geologists of the first survey to discriminate between the several beds of sandstone and limestone by lithologic characters only. It arose further, and perhaps especially, from the fact that neither he nor any of the geologists before him recognized that the true First or Saccharoidal sandstone has been quite generally removed from the central areas of the Ozark Plateau. The sandstones identified by Shumard and other geologists in these central areas, and also along the western border of the outcrop of the Magnesian series, are not the same as the true "Saccharoidal sandstone" on the eastern flanks of Ozarkia, as this ancient land has recently been called, but are in nearly all cases, as believed or suspected by Nason, older and much thinner beds. Some of them may belong to the Roubidoux, most of them probably to the Jefferson City limestone, while a few—particularly those at the contact with the overlying Devonian or Carboniferous rocks—are the initial deposits of much younger formations. As a rule, it may be stated that where no later Ordovician rocks intervene between the "Magnesian series" and the Devonian or lower Carboniferous beds that generally rest

[a] Nason, F. L., Report on iron ores: Missouri Geol. Survey, vol. 2, 1892, pp. 85–115.

on the eroded surface of the older magnesian limestones on the western and southern flanks of the Ozark uplift, the true "Saccharoidal sandstone" is missing entirely, it, together with more or less of the underlying limestone, having been removed by erosion prior to the Devonian and Carboniferous overlap. The long interval during which Ozarkia was elevated above sea level and subjected to erosion agencies was quite sufficient to remove the sandstone, since it comprised the later half of Ordovician, the whole of Silurian, and the greater part of Devonian time.

Winslow's table.—In 1894 Winslow published a table of formations in the lead districts of Missouri.[a] A number of new names for divisions of the rocks under consideration are contained in this table, and in the matter following the table brief descriptions of most of the formations are given. The whole series in the southwestern district is included under one name—White River limestone. This name had unfortunately been used and is in good standing for a Tertiary formation, and hence it is not available in this connection. Except for this fact it might very well have been employed instead of the name Yellville limestone recently proposed by Adams[b] for rocks in northern Arkansas holding precisely the same position as the rocks of the Magnesian series along White River. Along this river, however, the top of the series is minus both the Joachim (First Magnesian) limestone and the St. Peter (First) sandstone, while the lowest rocks outcropping belong to the Gasconade formation.

In Winslow's table the Magnesian or Ozark series in central Missouri is as follows, beginning at the top: Roubidoux or Saccharoidal sandstone, Jefferson City limestone, Moreau sandstone, Osage limestone, Cole Camp sandstone, and Proctor limestone. These formations presumably are equivalent to Swallow's divisions of the series in the same area, the only difference being that geographic names are used instead of lithologic. However, for reasons already pointed out, it was a mistake to employ Nason's name, Roubidoux, for the First or Saccharoidal sandstone instead of for the Second sandstone, which alone has a right to that name, and Roubidoux doubtless will displace the name Moreau, proposed by Winslow. As for the other names, Jefferson City limestone is proposed for Swallow's Second Magnesian limestone, Osage limestone for his Third Magnesian limestone, Cole Camp sandstone for the Third sandstone, and Proctor limestone for the Fourth Magnesian limestone. The last three divisions, as will be explained on a later page, all fall within the Gasconade limestone of Nason, according to the present writers' interpretation and definition of this formation.

[a] Winslow, Arthur, Lead and zinc deposits: Missouri Geol. Survey, vol. 6, 1894, p. 331.

[b] Adams, George I., and others, Zinc and lead deposits of northern Arkansas: Prof. Paper U. S. Geol. Survey No. 24, 1904, pp. 18–20.

In the third column of his table Winslow presents an altogether different subdivision and nomenclature, which is proposed for the series in southeastern Missouri. Beginning at the top, the formations are as follows: (1) Joachim limestone, this being the name proposed for the First Magnesian limestone of Swallow; (2) Crystal City sandstone, the geographic name proposed for the "Saccharoidal sandstone;" (3) Potosi limestone, which is assigned by Winslow to the interval corresponding to the Jefferson City limestone and Moreau sandstone in central Missouri; (4) St. Joseph limestone, which is placed opposite the Osage limestone, Cole Camp sandstone, and Proctor limestone, in the central Missouri column of the table; and (5) La Motte sandstone, which is placed at the base of the Ozark series.

Concerning the Joachim limestone and the Crystal City sandstone, the present writers believe these to be well-marked formations and properly correlated by their author. The Potosi limestone, however, corresponds to much more of the geologic column in central Missouri than is indicated by Winslow's table. As stated above, he made it correspond with only the Jefferson City limestone and the Roubidoux (Moreau) sandstone, while we regard it as including also the Osage limestone, the Cole Camp sandstone, and the Proctor limestone of central Missouri.

The St. Joseph limestone includes two easily distinguishable lithologic units. According to the view of the Potosi formation just expressed, both the Bonneterre and Elvins formations—the two beds comprised in the St. Joseph limestone—are distinctly older than the Proctor limestone, or its equivalent, the "Fourth Magnesian limestone" of Swallow. The stratigraphic relations and fossil contents of the successive beds in the sections studied by the writers in southeastern and central Missouri, it is believed, establish the truth of these opinions. For a brief discussion of these features of the problem the reader is referred to the remarks following the succeeding descriptions of the formations in question. As to the La Motte sandstone, probably all agree that the name was well chosen and that the formation itself is an excellently defined lithologic unit lower than all the limestones now comprised in the Ozark series.

Keyes's report.—In the year 1895, following Winslow's publication, Keyes published a report upon the section exposed in the La Motte quadrangle of Missouri.[a] In this area only the lower part of the Ozark series occurs. This he divides into three formations, the La Motte sandstone at the base, the Fredericktown dolomite next above, and the Lesueur dolomite at the top. All the beds of the last-named formation occurring in the La Motte quadrangle belong in the

[a] Keyes, Charles R., Missouri Geol. Survey Sheet Rept. No. 4, Mine La Motte, 124 pages. (Later bound in vol. 9.)

Gasconade limestone of Nason. The new name, therefore, was superfluous. It would seem to have been better to employ Winslow's rather broad term Potosi limestone. The name Fredericktown covers the same beds to which Winslow applied St. Joseph. The La Motte sandstone evidently is the same formation as that for which Winslow proposed the name.

Nason's later discoveries.—In 1901 Nason published a short paper on "The geological relations and age of the St. Joseph and Potosi limestones of St. Francois County, Missouri."[a] This paper contains at least three features of importance, viz: (1) The first description of a shale and conglomerate zone separating the St. Joseph and Potosi limestones, the discovery of which had been announced by the same writer earlier in the year;[b] (2) the announcement of the discovery by him of sufficient fossils from the conglomerate bed, which he attaches to the base of the Potosi limestone, to enable Dr. C. E. Beecher to determine the age of the bed as "Middle or Upper Cambrian;" and (3) the first publication in a scientific journal of recognized standing of the name "Bonneterre limestone."

Nason did not overestimate the stratigraphic importance of this conglomerate bed. Its base marks an important break, no less than that between the Upper and Middle Cambrian. A very similar contact, with almost exactly the same kind of conglomerate and fauna above it, commonly defines the limits of these two divisions of the Cambrian, not only in Missouri, but also in Indian Territory, central Texas, and at least locally in the upper Mississippi Valley. Classifying the "conglomeratic zone" with the Potosi is believed to have been a mistake, the writers preferring to make it the lower and greater part of a distinct formation, for which the name Elvins formation is proposed. Finally, the name Bonneterre limestone, used incorrectly and without comment as an alternative for Winslow's St. Joseph, is the most appropriate and probably the only strictly available designation for the limestone beneath the conglomerate of the Elvins formation.

Ball and Smith report.—An important contribution to the literature of the Ozark series appeared in 1903 in a volume by Ball and Smith on "The geology of Miller County."[c] In this report very full descriptions and numerous detailed sections are given of the formations corresponding, at least in a general way, to the Second, Third, and Fourth Magnesian limestones and the First, Second, and Third sandstones of Swallow's classification. The nomenclature

[a] Nason, F. L., Am. Jour. Sci., 4th ser., vol. 12, 1901, p. 358.
[b] Nason, F. L., Am. Jour. Sci., 4th ser., vol. 11, 1901, p. 396.
[c] Ball, Sidney H., and Smith, A. F., Missouri Bureau of Geology and Mines, 2d ser., vol. 1, 1903, 197 pages.

of the formations presented in this valuable work differs in several respects from that in the table on page 12 of this paper. For instance, the name Gasconade limestone is applied by the authors mentioned to Swallow's Third Magnesian limestone. According to our view, Nason, who is responsible for the name, included not only the Third, but the Fourth Magnesian as well, in his sections of the formation. The Gasconade limestone, therefore, if this name be used at all, should extend downward so as to include the Gunter sandstone and the Proctor limestone. This is not to say, however, that the Gasconade limestone in Miller County is not divisible into three members (or formations, perhaps), worthy of being mapped as separate lithologic units. Indeed, such a division seems not only practicable, but even very desirable through a large part of the northwestern half of the Ozark uplift. In the southeastern half, however, the two limestone members and the intermediate Gunter sandstone, though in a general way recognizable, do not seem to be as readily separated. Indeed, the Gunter sandstone, which is so definite a bed in Miller and adjoining counties, has entirely lost its identity or can not be distinguished from a number of similar sandstones occurring at about the same horizon. In Yell County, Ark., there seems to be no sandstone at all in the corresponding portion of the Gasconade. In Ste. Genevieve County, Mo., on the other hand, the upper half of the formation contains a number of sandstones, but it is impossible to say that any one is equivalent to the Gunter.

The St. Elizabeth formation of the Miller County report seems to be essentially, if, indeed, not exactly, the same formation earlier named Roubidoux sandstone of Nason.

As regards the "Pacific sandstone" of the Miller County report, which Ball and Smith correlate with the First or Saccharoidal sandstone of Swallow, it seems to the present writers highly improbable that it is the same as that outcropping at Pacific, Crystal City, and many localities on the eastern flank of the Ozark uplift. Some of the supposed occurrences of this bed may be thin lenses of sandstone in the Jefferson City limestone, but the majority probably are later than Ordovician—possibly Devonian or Carboniferous. At the top of one section (op. cit., p. 80) pieces of "dolomite resembling cotton rock" occurred above the sandstone. These, it is said, "may be remnants of the First Magnesian limestone," but, for many reasons which can not be given at this time, the whole exposure described on the page mentioned is believed to belong to the Jefferson City limestone. Finally, the name "Pacific sandstone" seems entirely unnecessary. If a Missouri name for the true Saccharoidal sandstone is preferred to the adoption of St. Peter sandstone, with which the First sandstone doubtless is identical, then it should be Crystal City sandstone, *a name proposed* by Winslow several years before.

GENERAL REMARKS ON THE "OZARK SERIES" OF ROCKS.

As has been already stated, none of the classifications and subdivisions of the Ozark series of rocks, briefly discussed in the foregoing pages, has proved wholly satisfactory. An arrangement that would be above criticism is perhaps impossible. Some of the beds vary so greatly from place to place that it is difficult to follow them over any considerable area. The difficulties are greatly enhanced by the apparent scarcity and imperfect preservation of the fossils and by the general similarity in lithologic character exhibited by widely separated beds in the series. The occurrence of beds of sandstone at intervals in the mass of magnesian limestones was early seized upon as affording a ready means for dividing the series into formations; but experience gradually taught that most of the sandstones were mere lenses, irregularly developed at unequal intervals and occurring locally as many successive beds or with only two or three. In the northern and central parts of the Ozark Plateau the sandstone beds seem to be more regularly developed than elsewhere, and here they are of considerable use in working out the stratigraphy. Along the southern border, however, only the First or St. Peter sandstone seems to have been so well developed as to mark a definite horizon. Along the eastern border, especially in Ste. Genevieve County, the upper half of the series is thicker than usual. It here contains so many beds of sandstone that it is very difficult to establish the boundary line between the Gasconade and Roubidoux formations and between the latter and the overlying Jefferson City limestone.

A careful study of the cherts has yielded perhaps the most reliable of the lithologic criteria employed in discriminating the three formations of the Potosi group. As this group covers by far the greatest part of the Ozark area, the opportunities for studying and testing the value of certain varieties of chert as indices of particular horizons are unusual. Having checked the results in many instances by evidence afforded by fossils, which really are much commoner in these rocks than is generally believed, we have gradually become convinced that the story as told by the cherts is rarely at fault. The mere presence of considerable quantities of chert is at once reliably indicative of the Potosi group, the underlying limestones being practically free from it, as is true also of the Joachim limestone at the top of the series. It is to be remembered, however, that the proportion of chert in a given bed may vary greatly in near-by exposures. This is shown often very strikingly in opposite faces of a hill, the one side of which forms a bluff, the other a gentle, soil-covered slope. In cases of bluff exposure—where side erosion is active and takes place under conditions very different from those prevailing on gentle slopes—the limestone beds may often seem to be almost entirely with-

out chert, but on the other side of the hill the surface may be thickly strewn with it.

The classification presented in tabular form on page 12 is based upon more or less extended investigations in all parts of the field. The formations are discriminated chiefly by lithologic differences, and limited in most cases by at least local stratigraphic discordances. As the formations are intended to express as much as possible lithologic units deemed worthy of being mapped separately, the evidence of the fossils found in them was accorded secondary rank. However, in the determination of the age of the deposits the faunas were depended upon almost exclusively.

It will be observed that the division between the Ordovician and Cambrian is drawn as a dotted line opposite the Roubidoux member of the Potosi. This seeming indecision concerning the point at which the line should be drawn is not due to the absence of a fauna, for we have succeeded in collecting a large one, but because of the conflicting elements contained in it. The trilobites from the Gasconade and the lower part of the Roubidoux are, so far as observed, nearly all of types that hitherto have been regarded as strictly indicative of the Upper Cambrian. On the other hand, the numerous gasteropods and fewer brachiopods found in the same beds are nearly all of Lower Ordovician types.

DESCRIPTION OF FORMATIONS.

LA MOTTE SANDSTONE.

This formation generally consists of thick, massive beds of sandstone. Toward the top it is often thinly bedded or flaggy. The color of the sandstone is usually yellow or reddish brown, with occasional layers almost white. It is generally composed of large grains of quartz in a matrix of smaller grains. In the upper half of the formation the matrix is often calcareous, the proportion of limy material usually increasing upward until the rock grades into a sandy limestone. Near the top beds of limestone may alternate with layers of sandstone, and in such cases the transition to the overlying Bonneterre limestone may be gradual. Near the base there are frequently layers containing coarse grit and quartz pebbles and others with small pebbles of granite and porphyry. The upper beds are often chloritic, but so far as observed no part of the formation is ever micaceous.

The maximum thickness of the La Motte sandstone is not less than 250 feet, and in the bottoms of the basins adjacent to granitic areas, which doubtless were the main sources of supply, the thickness probably exceeds 300 or possibly 400 feet. From this it dwindles down to

nothing along some of the old shore lines, where it is overlapped by the limestones of the next formation.

The principal areas of outcrop occur around the granite hills in the western half of Ste. Genevieve County and on the eastern flanks of the old Archean hills in Madison and St. Francois counties. How far from these areas this formation extends beneath the covering of higher rocks can not now be said. Possibly it is widely distributed, and it may even be continuous with what is believed to be nearly contemporaneous Middle Cambrian sandstones in Indian Territory and in the upper Mississippi Valley. However, considering the granitic rocks in southeastern Missouri as the principal if not the only source from which its quartz grains might be derived, it does not seem likely that the formation—at any rate, as a sandstone—could have attained any considerable thickness far from its present main outcrops. Masses of quartzite, etc., occurring apparently at the base of the Bonneterre limestone in the southern part of Camden County, where profound disturbances have brought this limestone to the surface, may be silicified blocks of a thin extension of the La Motte sandstone.

In the area of the St. Francis Mountains a conglomerate, consisting mainly of pebbles of porphyry in a slaty or sandy matrix, often underlies the La Motte sandstone. In the Missouri Survey reports this bed is referred to under two names—Pilot Knob conglomerate (Keyes) and Iron Mountain conglomerate (Winslow). The age of the bed is variously interpreted, some considering it, especially at Pilot Knob, as Algonkian; in other cases it seems not to be older than the lower part at least of the La Motte sandstone. The truth of the matter probably is that the conglomerate is primarily the initial deposit of the invading early Cambrian, and that during the subsequent deposition of the La Motte sandstone the conglomerate continued locally to be formed near the shore, perhaps more particularly where this was steep. The bed, therefore, it not to be regarded as a formation wholly beneath and older than the La Motte sandstone.

BONNETERRE LIMESTONE.

As a rule this formation consists of more or less heavily bedded, granular, and highly magnesian limestones. In texture these generally are compactly crystalline and often minutely vesicular, with dolomite crystals lining the cavities. A few beds are fine grained. The usual color is light or dark gray, especially when fresh, a yellowish tint being commonly acquired on weathering. Locally the mass may contain beds of a pink or of a more decidedly red color. Chert and drusy quartz seem to be entirely absent. Some of the beds, especially in the lower part of the formation, contain much chlorite, in places sufficient to give them a decidedly green color.

Toward the base of the formation it contains some silica. This occurs as grains of sand in the limestone. The contact with the underlying La Motte sandstone is rarely sharp, the two formations often appearing to grade into each other. The basal portion commonly also includes one or more thin beds of bluish shale. Where the top of the formation has suffered least from the widespread erosion that took place prior to the deposition of the Elvins formation it grades upward from the massive limestones into a thinly bedded zone, and this finally into a bed of blue shale. Locally the thinly bedded and shaly zones appear to be absent entirely.

Fossils are rare in this formation, except in the shaly bed near the base. This is crowded with a species of *Lingulepis*, related to *L. lamborneí* Meek. Fragments of other fossils occur with this shell. A few specimens of trilobites and of orthoid shells related to *Billingsella* were observed also in the shales at the top of the formation. These fossiliferous horizons, however, have not been thoroughly exploited. The species so far found are comparable to those characteristic of the Middle Cambrian.

Like the La Motte sandstone, this formation varies greatly in thickness, and seems even to wedge out on the old hillsides. In the vicinity of Mine La Motte and Fredericktown, where the basin is comparatively shallow, the maximum thickness probably does not exceed 200 feet, or possibly 250 feet. Farther north, in St. Francois County, deep drillings show it to be much thicker, the greatest thickness probably being nearly 500 feet. Winslow gives the maximum thickness in the vicinity of Flat River as "somewhere near 600 feet," but this estimate doubtless includes the whole, or at least a large part, of the overlying Elvins formation.

The Bonneterre limestone is the prevailing surface rock in the southeastern lead-mining district of Missouri. The formation probably underlies a large part of the Ozark uplift, but it does not again come to the surface within the borders of the State except in a small area near the southern boundary of Camden County. Here it occurs as a noncherty, massive, crystalline dolomite, standing nearly on edge about a dike of graphic granite. On account of the excessively disturbed character of the outcrop and the brevity of the time devoted to its study, the thickness of the formation was not determined exactly. It is safe to say, however, that it is not less than 200 feet.

That the base of the formation is exposed at this locality is indicated by the presence of a bed of limestone filled with rounded grains of quartz and of quartzite bowlders believed to be silicified masses of La Motte sandstone. Closely associated with these, and apparently overlying the calcareous sandstone, is a bed of fine conglomerate *that is believed* to be the basal layer of the Bonneterre limestone.

The pebbles in this conglomerate consist principally of greenish-blue shale and fragments of limy sandstone abundantly specked with a green mineral supposed to be chlorite.

In southeastern Missouri, except in the few places where the formation overlaps the underlying sandstone and rests on the Archean, the base seems to be entirely conformable with the top of the La Motte sandstone. The upper boundary, however, as intimated above, is variable. Sometimes there is a considerable body of thin limestones interbedded with shale at the top that at other points is much thinner or perhaps may be wanting entirely. This irregularity of the top is due to an erosion interval, in which much of the shaly top of the formation was removed. There is, consequently, an unconformable contact between the Bonneterre and Elvins formations. In the outcrops, which occur chiefly in the marginal portions of the old basins, this unconformable contact is marked by one or more thin beds of lenticular pebbles. Where observed it generally occurs within what might otherwise appear as a continuous deposit of rapidly alternating thin limestones and shales. On this account it may be difficult, and in some cases impossible, to distinguish the upper part of the Bonneterre formation from the Elvins formation in records and cores of drill holes. In the outcrops, however, the boundary between the two may be drawn with little trouble. Considering that this line probably separates the Middle Cambrian from the Upper Cambrian, and that it may eventually mark the boundary between two systems, its stratigraphic importance becomes clear.

ELVINS FORMATION.

This name is proposed for the shales, shaly limestones, and more or less earthy dolomites that in St. Francois County intervene between the shaly top of the underlying Bonneterre limestone and the cherty limestones of the Potosi group above. In the vicinity of Elvins and Flat Rock the base of the formation is marked by a zone 6 to 10 feet thick, consisting mainly of indurated platy shale. At the bottom of this zone is a layer, generally only a few inches in thickness, that is largely made up of lenticular pebbles usually arranged edgewise in a subcrystalline limy matrix. At the top of the zone there is usually a similar "edgewise layer," while between the two layers one or more smaller lenses of conglomerate may be observed. In the Elvins section given on pages 24–25 a bed of nearly white, compact, and apparently not highly magnesian limestone occurs about 8 feet above the base of the formation, which is well exposed in the railroad cut a half mile north of the Illinois Southern Railroad depot at Elvins. In the unfinished deep cut nearer the depot

this layer is broken up into a series of large, bowlder-like masses that may be of concretionary origin.

The following detailed section of the typical exposures of the formation will give a better idea of the lithologic and other characters than could be acquired from a general description:

Section of the Elvins formation along the Illinois Southern Railroad between Elvins and 1 mile north.

Serial No. of beds.	Thickness.	Description of beds.	Thickness.
	Ft. In.		Ft. In.
		Slope to top of hill covered abundantly with characteristic Potosi chert and masses of drusy quartz.	
		A bed of massive, pink, granular dolomite, without chert, regarded as the basal layer of the Gasconade limestone (about 4 feet).	
9	6 0	Light-yellow to grayish-blue, apparently slightly arenaceous, magnesian limestone, in thin, even beds. Bedding planes with fucoids, small cavities lined with crystals of calcite and dolomite in rock	6 0
8	26 6	Very thinly bedded, earthy magnesian limestone. Near by this appears nearly solid. Two layers, one 6 feet, the other 11 feet beneath top, contain numerous but very poorly preserved fossils. These consist chiefly of fragments of crinoids or cystids	17 0
		Subcrystalline, brownish dolomite	0 6
		Upper and lower thirds shale, middle third thinly bedded earthy magnesian limestone	9 0
7	17 3	Yellowish, cellulose dolomite in thin, rough layers	0 9
		Shale	0 10
		Yellowish, cellulose magnesian limestone	3 0
		Shale	1 0
		Earthy magnesian limestone or dolomite	2 5
		Yellowish to light-blue soft shale. Upper Cambrian trilobites in limestone concretions	4 0
		Earthy magnesian limestone with lenticular pebbles	1 3
		Shale resembling and containing fossils like those in shale next above	4 0
6	10 0	Dolomitic limestone, rather thinly bedded, locally containing lenticular pebbles and a few fossils	10 0
5	11 0	Blue shale with irregular lenses of dolomitic limestone near middle	9 0
		Dolomitic limestone	2 0
4	22 0	Bluish shale with four or five layers of limestone ranging from 3 to 12 inches in thickness	15 0
		Interbedded dolomitic limestone and thinner layers of shale	7 0

Section of the Elvins formation along the Illinois Southern Railroad between Elvins and 1 mile north—Continued.

Serial No. of beds.	Thickness.	Description of beds.	Thickness.
	Ft. In.		*Ft. In.*
3	10 0	Blue shale, increasing in hardness downward	6 0
		Soft clay shale. This rests on the white limestone beneath or, where that layer is broken up into bowlder-like masses, it fills the intervals between them	4 0
2	0–3 0	White, compact, apparently not highly magnesian limestone, occurring either as a continuous layer or as bowlder-like remnants embedded in shale. The "remnants" are usually flat on the lower side and rounded above	0–3 0
1	8 0	Indurated, platy shale, with a layer of "edgewise conglomerate" at the base and often another at top. (Base of the formation)	8 0
		Total thickness of Elvins formation	113 9

Beneath these beds the upper part of the Bonneterre limestone shows as follows:

Section of Bonneterre limestone exposed along railroad between Elvins and 1 mile north.

Serial No.	Description of beds.	Thickness in feet.
2	Bed here forming top of Bonneterre limestone. It is similar to the basal bed of the overlying Elvins formation, except that it contains more soft shale and thinner hard layers; also an occasional thin seam or lens of crystalline limestone with fossils of apparently Middle Cambrian types	10
1	Impure magnesian limestone and shale, growing on the whole more calcareous downward in first 20 feet; then a shaly bed, and finally more limestone, passing gradually into the normal type of Bonneterre limestone; exposed in the bed of Flat River	30–40

The lower part of this formation was well described by Nason in 1901.[a] This writer also was the first to observe and note the importance of the beds of conglomerate marking the base and occurring also higher in the lower formation. Ranking the new horizon as a lower division of the Potosi limestone is believed to be an error, because (1) it constitutes a sharply defined lithologic unit; (2) its fauna is very different from that of the Potosi group, in wanting all the molluscan types which distinguish the Potosi from

[a] Nason, F. L., Am. Jour. Sci., 4th ser., vol. 12, 1901, pp. 358–361.

all preceding rocks; and (3) it seems that the contact with the overlying Potosi is, at least locally, unconformable.

The bed of pink dolomite assigned to the base of the Potosi in the foregoing section contains no chert nor drusy quartz, and in that respect differs decidedly from the overlying beds of the formation. It may therefore be regarded as more properly referable to the Elvins formation. This is not here, for the reason that it or a similar bed inaugurates the Potosi sedimentation in areas where the Elvins formation is wanting. The similarity in lithologic character of the bed to the underlying rather than the overlying limestone is believed to result from a reworking of nonsiliceous matter derived from the dissolution of the underlying limestones. Beds above and beneath nearly conformable contacts are often very similar lithologically. The contact between the Bonneterre and Elvins formations affords a striking illustration of this.

Outcrops of the Elvins formation occur principally within St. Francois County. Here they are found in the slopes of perhaps all the hills that are capped by the residual cherts of the Potosi. The formation is frequently noticed also in drill holes in this county. In the northern part of the county these holes frequently pass through from 160 to as much as 250 feet of shales and chertless limestone, thus indicating a greater thickness for the formation than is found in the section measured at Elvins. However, it is at present not possible to say how much of these shaly beds underlie the conglomeratic layers and thus belong to the Bonneterre formation. On Rock Creek, east of Mine La Motte, no sign of the Elvins formation was observed, and the Potosi rested directly on the Bonneterre limestone.

POTOSI GROUP.[a]

The group of rocks included between the Elvins formation beneath and the St. Peter ("Crystal City") sandstone above is characterized by large quantities of various kinds of chert and drusy quartz. The group includes mainly limestones, nearly all more or less highly magnesian, the proportion of magnesia in some cases approximating that contained in a theoretical dolomite. Intercalated with the limestones, especially in the upper half or two-thirds of the series, are more or less irregularly developed and usually thin lenses or beds of sandstone.

[a] Winslow is responsible for the name Potosi as applied to a geologic formation. Unfortunately, in the original publication (Missouri Geol. Survey, vol. 6, 1894) the formation is not clearly defined, and as a rule its beds are referred to under the broader term St. Francois limestone. There is, therefore, some chance of conflict with the term Lesueur limestone proposed by Keyes the year following for essentially the same rocks. Most geologists and mining experts who have studied the Ozark rocks in southeastern Missouri have consistently used the name Potosi in the sense here adopted. This accords with Winslow's original intention as well as with his later definition of the *term.*

As the group forms the surface rock over quite nine-tenths of the large area of Ozark rocks in Missouri and northern Arkansas, it is highly desirable to subdivide it into such formations and members as may be required to illustrate the stratigraphy and structure of the region. Where the sandstone beds are fairly persistent, as in nearly the whole of the northwestern half of the area, they afford convenient datum lines upon which to base the desired subdivision. Careful use of certain types and beds of chert likewise aids in accomplishing the purpose.

Building upon the combined results of the efforts of Nason, Winslow, and Ball and Smith, we have recognized three major divisions that we believe may be carried with more or less accuracy over much the greater part of the territory in which the group is at the surface. These are, (1) the Gasconade limestone, at the base; (2) the Roubidoux formation, in the middle; and (3) the Jefferson City limestone, at the top. In the central and northern parts of the area the Gasconade limestone is further divisible into an upper and a lower limestone formation or member by an intervening thin but widely distributed and easily identified sandstone member, called the "Cole Camp sandstone" by Winslow and the "Gunter sandstone" by Ball and Smith. Locally other subdivisions are possible, and in the final mapping will doubtless be made.

During practically the whole of Potosi time the waters of the sea in the region now exposing the rocks of this age were shallow and fluctuating in depth. Frequently the bottom was raised above sea level, or it may be that the waters subsided and thus caused the bottom to be exposed. These emergences were more or less local and, according to the evidence available, must have varied greatly in the length of time through which each endured. Evidences of this condition are abundant. Intraformational conglomerates, sun-cracked beds, oolites, unconformities due to exposure and erosion, and cases of abrupt change in deposition from limestone to sandstone all occur frequently. The conglomerates in many cases indicate a considerable lapse of time. This is more particularly indicated for those containing pebbles of chert. Chert was only rarely present in this group of rocks when they were originally deposited. As it now occurs it is largely the result of segregation of siliceous matter under conditions of slow subaerial decomposition of the limestone. Hence the presence of rounded chert pebbles is strongly indicative of subaerial erosion and, for obvious reasons, of a longer time interval than is usually ascribed to an intraformational conglomerate. In these features the deposition of this part of the Ozark series differs from that of the corresponding parts in the Arbuckle limestone of Indian Territory and the Knox dolomite of the Appalachian Valley. The latter rocks were laid down in comparatively

deep basins, while those of the Potosi group were spread unevenly over the summit of a low, broad dome. This explains also the occurrence in Missouri of a considerable fauna, whereas the corresponding deposits made in deeper waters are almost or entirely devoid of fossils. The Cambrian and early Ordovician faunas flourished only in shallow waters and along shore lines.

The shallows of the Ozark area afforded the necessary conditions for life, and here the main types of the Upper Cambrian fauna—especially the trilobites—continued in existence longer, while the Lower Ordovician fauna began earlier than is indicated elsewhere by faunas hitherto discovered.

As the copper deposits which constitute the principal subject of this contribution are contained, with one exception, in the rocks of this group, the major subdivisions will be described in some detail.

GASCONADE LIMESTONE.

In the report on Miller County, discussed earlier in this paper, the name Gasconade is restricted to the Third Magnesian limestone of Swallow. This makes it the same as the Osage limestone, proposed in 1894 by Winslow as a subdivision of the Gasconade limestone. The term Osage, however, had been used by Williams and Branner some years before for a group of Mississippian rocks, and, for this reason no doubt, Winslow's use of the name was objectionable to the authors of the Miller County report. Nason is responsible for the term Gasconade limestone. As adopted by Winslow, it became too broad, being placed opposite all the limestones beneath the Crystal City sandstone. This expansion of the meaning of the term was caused by the erroneous assumption that the Roubidoux and St. Peter sandstones were equivalent deposits. As employed here the Gasconade limestone embraces the chert-bearing limestones and included sandstones underlying the true Roubidoux, as determined by studies of some of Nason's typical localities, and overlying the strictly non-cherty limestones of the Elvins and Bonneterre formations. This conception of the Gasconade, it is believed, is in accord with Nason's intention. As his deepest sections, along the Current River, in Shannon County, undoubtedly contain at least the upper part of the Proctor limestone, which is the basal member of the formation, we have, as is usual in such cases, drawn the lower limits of the formation at the first well-marked stratigraphic and lithologic change beneath the rocks included in the formations by Nason.

The Gasconade limestone consists chiefly of dolomitic limestone, varying greatly in color and composition and somewhat less in texture. The color of the majority of the beds is gray, in lighter and darker shades. Sometimes a bluish tinge is observable, but light-*pink tints* are more common. Other beds may be brown, green, or

nearly white. As a rule, it may be said that bluish tints are more common in the lower parts than in the upper. The prevailing texture of the limestone rock is medium to coarse grained, crystalline, or granular, but comparatively fine-grained layers occur, and perhaps as commonly in one part of the formation as in another.

Several beds of sandstone occur, most of them small sporadic lenses in the upper half of the formation. One bed, the Cole Camp sandstone of Winslow and the Gunter sandstone of Ball and Smith, is more than usually persistent in the central and western parts of the area. In these districts its thickness ranges from 2 or 3 feet to 25 feet, and, as it is nearly always exposed, it constitutes an efficient boundary line between the Proctor limestone and the upper (Osage) limestone of the formation. The other divisions are more likely to confuse than help the geologist in working out the stratigraphy. In the southern part of the Ozark area the Gunter sandstone, in common with the other sandstones interbedded with the limestones of the Potosi group, is either absent entirely or so irregularly developed that it has lost its stratigraphic value. On the east side of the St. Francis Mountains, in Ste. Genevieve County, this sandstone bed is probably represented, but there are so many sandstones in the Potosi of this region that it can not be certainly distinguished.

Under usual conditions of subaerial decomposition the silica of the rocks is segregated in the form of amorphous and lamellar or vesicular chert, or as drusy quartz, in nearly all parts of this formation. However, under the present physiographic conditions, chert is on the whole more abundant in the upper part of the formation than in the lower, but this difference seems not to be due to any marked variation in the composition of the limestones composing the two parts, but results rather from differences in the circumstances attending the decomposition and erosion of the upper member and those prevailing in the case of the lower. As is briefly suggested on page 27, rapid erosion is not conducive to the abundant segregation of chert. Therefore the lower, or Proctor, limestone, being rarely seen in the central area except in bluffs, appears to be characterized here by having much less chert than the upper division, which more commonly occupies upland ridges. In areas where the valleys are occupied by the Bonneterre limestone and the hills by rocks equivalent in age to the Proctor limestone, as in St. Francois and Madison counties, chert is extremely abundant in the lower as in the higher parts of the formation. It appears, therefore, that local superficial conditions are responsible for much of the unequal distribution of the chert.

Lamellar chert with drusy cavities occurs very abundantly in the lower and middle parts of the formation, but is comparatively rare in the upper beds. A highly characteristic form of chert, consisting of irregular rough stems, one-half inch or so in diameter, bound

together by anastomosis into masses a foot or more in length, was observed at many localities. It occurs commonly enough beneath the horizon of the Gunter sandstone, but is especially abundant in the first 50 feet above that bed.

The cherts of the upper division embrace two common varieties that are believed to characterize this horizon over a large part of the Ozark area. They are both laminar varieties, and possibly of organic origin. One is a "*Cryptozoon*," differing from the *C. minnesotensis*, which is characteristic of the Jefferson City limestone in its looser and more irregular structure. The other is a very coarsely vesicular form, occurring in masses 2 or 3 feet thick and making up whole layers of that thickness. When followed into the bank these layers gradually pass into solid limestone, but even in these a similar horizontal lamination of the mass is observable. The laminæ are divided at intervals of about 2 inches into convex, minutely cellular plates, arranged one above the other so as to leave open spaces about equal to the thickness of the plates between them. This type occurs principally toward the top of the formation and is a reliable guide to one of the most prolific fossil horizons of the whole series. Thin conglomeratic layers, containing small chert pebbles and fragments of silicified and often sandy oolite, both commonly fossiliferous, occur with and above this coarsely vesicular type of chert.

Fossils occur more or less sparingly through all parts of the formation, but are generally distributed and of larger size in the upper beds. They consist chiefly of low-spired and ventricose species of Gasteropoda. Associated with these are many fragments of trilobites, having unmistakable affinities with well-known Upper Cambrian species. Toward the base of the formation the fossils are sometimes abundant, but the species seen are not numerous, and, being small, are easily overlooked.

In thickness this formation varies considerably from place to place. The greater amount of this variability seems to occur in the upper member, which was laid down under less uniform conditions than the lower. Locally, in St. Francois and Madison counties, the lower member also is thinner than usual, the variation in this case appearing to be due to overlap and consequent absence of the basal beds. The average thickness, doubtless, is at least 500 feet for the whole formation, while the maximum thickness probably exceeds 650 feet.

Concerning the relations of the Gasconade limestone to adjacent formations, it may be said that the basal contact is believed to be rather generally unconformable. It is certainly so locally, as is shown by the occurrence of certain fossiliferous bands, local evidence of overlap, and a comparison of the basal beds in different sections. However, on account of the abundant wash from overlying beds, exposures showing the contact in a satisfactory manner are very rare. In Cam-

den County, where the base is shown in the vicinity of the pegmatite dike, a massive white sandstone, 20 to 30 feet thick, intervenes between the Bonneterre limestone and the cherty limestone of the Gasconade. This sandstone is probably to be regarded as the initial deposit of the Gasconade or possibly as in part representing the Elvins formation.

The top of the formation is less sharply defined; indeed, it is often difficult to draw the line between it and the Roubidoux. There is no important unconformity between the two, the shallowing of the seas, which continued throughout and attained its culmination in the Roubidoux, having also prevailed in a less but increasing degree during Gasconade time.

ROUBIDOUX FORMATION.

This interesting formation is extremely variable in its lithologic characters. It is, as described by Ball and Smith,[a] who called it the St. Elizabeth formation, "a complex consisting of beds of sandstone, chert, quartzite, dolomite, and shale, all of very uncertain thickness and areal extent." Locally, as south of the Osage River in Miller and adjoining counties, one of the sandstones is sufficiently persistent and well developed to warrant mapping it as a distinct member. In Miller County this member has been distinguished under the name Bolin Creek sandstone.

The dolomites of this formation are prevailingly thin bedded, fine grained, dense, and hard. In texture and conchoidal fracture they simulate chert. Beds of "cotton rock," an argillaceous, compact, fine-grained and comparatively soft dolomite, are not uncommon. This variety of rock is nearly always thinly bedded, of a light-yellowish or buff color, and generally exhibits dendritic markings on the bedding planes. Thin layers of shale are often associated or interbedded with it. Although beds of coarse- or medium-grained dolomite are occasionally found in this formation, it will be noted that, on the whole, the dolomites are conspicuously different from those constituting the bulk of the Gasconade formation.

Chert is found in greater abundance in the calcareous portions of this formation than in any other of this great series of dolomitic limestones. It occurs in various forms, the brecciated, conglomeratic, and cellulose or "honeycombed" varieties being the most common. Certain varieties found in the underlying and overlying formations, particularly those containing drusy cavities, are notably absent.

Perhaps the most marked and widely distributed type occurs at or near the base of the formation. Because of its position it aids materially in locating the boundary between the Roubidoux and the Gasconade. This chert is of dense structure and brittle and ranges

[a] Geology of Miller County: Missouri Bureau of Geology and Mines, 2d ser., vol. 1, 1903, p. 50.

in color from nearly white to dark gray or even black. It is always brecciated and splintered, and the angular fragments, having been subsequently recemented by quartz or limonite, now form large rugged masses and often thick beds. This bed has been observed in Miller, Camden, Shannon, Franklin, and Ste. Genevieve counties.

Another variety that is locally of service in recognizing the upper part of the formation is distinguished by its cellular character. Similarly honeycombed chert, however, has been observed in the Gasconade formation in Shannon County, so that it is not strictly characteristic of the Roubidoux. The conglomeratic variety, which is largely made up of small, rounded, and often lenticular pebbles of chert, and commonly with admixtures of quartz and oolite grains, likewise occurs in the upper part of the underlying formation. This was found to be the case more especially in Shannon County.

The beds of sandstone found in this formation are its most variable part. Sometimes, particularly in the region west of Ste. Genevieve, where there are many such, the individual beds range in thickness from a few inches to over 30 feet. They vary greatly also in size of grain, color, and other features, but in these respects afford no means for distinguishing them from the occasional beds occurring in the Gasconade formation. Nevertheless, they very commonly exhibit certain features, such as thin and distinct bedding, ripple-marked and sun-cracked surfaces, and occasionally fucoidal markings, that together reliably indicate this horizon. Another peculiarity that was noted in many places is the presence, often in great number, of light-colored, flattened, apparently argillaceous pebbles, or of lenticular spaces resulting from their disintegration and removal.

Fossil remains are not uncommon in most of the cherts and in some of the sandstones of this formation. They are, however, but rarely in a good state of preservation, the most of them having been macerated before being covered by deposits, while all have suffered from subsequent changes in the rocks. The species consist mainly of gasteropods. In most cases they are closely related to, if not the same as, those found in a more favorable condition in the upper part of the underlying formation. A neat undescribed form of *Helicotoma*, characterized by revolving rows of small nodes on the upper and lower sides of the volutions, appears for the first time in this formation and may be confined to it.

There is in some places evidence of unconformity, and hence of an erosion interval, at the contact between this and the underlying Gasconade formation, but the fact is of less importance than usual. As stated on page 31, the shallowing of the seas with its attending phenomena had already begun in the preceding age, and merely attained its full and almost continuous expression in the Roubidoux. As the *bottom of the* sea could not have been perfectly flat, it is obvious that

phenomena indicating periodic shoaling and local elevation above sea level must be correspondingly local in their extent. The Roubidoux stands for a condition rather than a time period, and as this condition must have been fully established in some localities a little earlier than it was in others, the lower boundary can not be everywhere drawn at precisely the same point. The case is similar with respect to the upper limits of the formation, except that here the phenomena took place in reverse order. Despite these facts, it is believed that the whole area under discussion was so nearly level through the greater part of Potosi time, and especially during this portion of it, that the Roubidoux may be defined and mapped so that it will represent an interval bounded both above and beneath as accurately as it is practicable to measure geologic time.

Considering the conditions under which this formation was deposited, it is to be expected that it would vary considerably in thickness from place to place. The minimum thickness, as reported by Ball and Smith (op. cit., p. 52), occurs near Iberia, where it is said to be only 70 feet thick. In Miller County the thickness ranges from 70 to 160 feet. However, the average thickness for this county, as well as for nearly the whole of the central part of the Ozark area, is between 100 and 125 feet. In local basins along the border of the area, as in the region between Ste. Genevieve and the Jonca granite hills, the thickness of the beds referred to the formation probably exceeds 225 feet.

Concerning the name of the formation, there seems to us to be no chance for reasonable doubt that Nason's Roubidoux, as based on his sections along the Osage and Current rivers, is essentially, if not exactly, the same as the St. Elizabeth formation of Ball and Smith. The only reason for doubting their equivalence is Nason's erroneous suggestion, subsequently adopted by Winslow, that the Roubidoux is represented in the counties along the Mississippi by the St. Peter ("Crystal City") sandstone. Other synonyms are indicated in the table on page 12.

JEFFERSON CITY LIMESTONE.

This formation consists principally of various kinds of dolomitic limestone. Interbedded with these are a few thin beds of sandstone, occurring chiefly in the lower part, thin beds of shale, and even thinner layers of chert. Nodules of concentrically banded, dense chert, most of them conforming with the doubtful organism known as *Cryptozoon minnesotense*, occur usually in considerable abundance in the residual clays. These nodules, which often contain drusy cavities lined with small quartz crystals, are characteristic of the forma-

tion. The topography of areas in which the Jefferson City limestone outcrops is always less rugged than that of areas in which the two formations next beneath are exposed. Not uncommonly the undulations of the surface are gentle enough in these areas to justify classing them as prairie lands.

The majority of the Jefferson City limestones belong to two varieties, namely, "cotton rock" and medium-grained, massive dolomite. The cotton rock is an argillaceous, siliceous rock, usually containing over 40 per cent of magnesia. It is relatively soft, with a fine-grained, earthy or clayey texture and conchoidal fracture. In color it varies from white or yellow to buff and gray. It is nearly always thinly bedded, with the bedding planes even and often exhibiting dendritic markings. Thin shaly partings are common. This variety of stone occurs locally and in limited quantity also in the Roubidoux formation, but the much greater development of cotton rock in the Jefferson City limestone affords probably the readiest of the criteria employed in distinguishing the two formations. The beds of cotton rock range in thickness from less than a foot to over 30 feet, and they may occur at any horizon in the formation.

On weathering, the surface of the massive dolomite assumes a peculiarly pitted or hackly surface that is sufficiently characteristic to be distinguished from that of the "pitted" dolomites found in lower members of the group.

Chert occurs less abundantly in the Jefferson City limestone than in the preceding formations of the Potosi group. Occasionally beds of brecciated chert occur in association with silicified oolites and sandstone, but these seem to be confined to the lower 100 feet. The Ste. Genevieve copper deposits occur in such a bed. The commonest and at the same time the most characteristic form of chert found in the formation is the "*Cryptozoon minnesotense*" variety already mentioned.

A number of generally very thin and irregularly distributed beds of sandstone, occurring chiefly in the lower 100 feet, are included in this formation. The thickness of the heaviest of these beds rarely exceeds 5 feet, the others ranging down to 1 inch. Often they contain enough calcareous matter to be called arenaceous limestones. Most of them are medium grained and friable, but here and there one may be found that has been silicified into a hard quartzite. The color is usually a reddish brown, but yellow and white beds are not uncommon. Locally some of the heavier beds contain pebbles of chert and dolomite.

The Jefferson City limestone is the surface rock over a large portion of the two marginal ranges of counties embraced in whole or in part within the Ozark area. Along the western and southwestern borders of the area and in most of the outliers in these parts of the

State, the Jefferson City limestone is the youngest of the formations of the Ozark series remaining, the others having been removed prior to the deposition of the Devonian and Carboniferous rocks, which usually rest unconformably on the older series. The St. Peter or First sandstone, and the Joachim or First Magnesian limestone, so far as our observation extends, are wanting in every case where either the Chattanooga shale or one of the basal members of the Boone formation is in contact with the Ozark series. The First sandstone has been seen only in sections containing some later representative of the Ordovician, while the Joachim outcrops only along the eastern border of the area, where the Plattin limestone of the Stones River group is present. Both the First sandstone and the First limestone of the series have been heretofore widely identified in the central and western parts of the Ozark area, but the beds so correlated belong in every case examined to the Jefferson City limestone.

The upper beds being absent in the areas where the Jefferson City limestone is at the top of the series, the total original thickness of the formation in such localities can not now be determined. Where it is overlain by the St. Peter sandstone, as it is along the eastern and northeastern portions of the border of the Ozark area, the maximum thickness of the formation probably exceeds 250 feet.

As has been said in the remarks on the Roubidoux formation, the conditions of shallow waters and frequent fluctuations of sea level that prevailed so constantly during the deposition of that variable series of beds gradually gave way to the gentle subsidence that obtained in this age. Shallows still prevailed in the earlier portion of the age, and it is in strata then laid down that a considerable and mostly characteristic fauna is to be found. In the middle and upper parts of the formation, however, fossils are either very rare or wanting entirely. This fact is believed to indicate that subsidence had progressed to such an extent that the shallow-water organisms of the time became locally extinct.

At the close of the epoch the area was again elevated and, in places at least, sufficiently emerged to be subjected to erosion. The contact with the St. Peter sandstone in such localities is distinctly unconformable.

ST. PETER ("CRYSTAL CITY") SANDSTONE.

This is the well-known true "Saccharoidal "sandstone. It outcrops in fine typical exposures at Crystal City and Pacific, at which places it is being worked for glass sand, and at numerous localities in Ste. Genevieve, Perry, and Cape Girardeau counties. The formation has been so often and so well described that it is unnecessary to give any further description here. It may be worth while, however, to say that in the opinion of the writers the Crystal City, Pacific,

and Cap-au-Grès sandstones are unquestionably the same formation as the St. Peter sandstone of the upper Mississippi Valley.

Remarks concerning the distribution of this sandstone in Missouri will be found on page 19.

JOACHIM LIMESTONE.

This formation rests conformably on the St. Peter sandstone. The contact between the sandstone and the limestone seems, as a rule, not to be sharp, a certain amount of gradation occurring in all cases observed. Above these basal beds the formation usually consists of yellow and buff to light-gray, thinly bedded magnesian limestone, alternating with beds of compact, brittle limestone. Locally thin beds of sandstone, rarely quartzose, are interbedded with the limestones. Fossils have not been observed, except in a single bed occurring about 60 or 70 feet above the base. This is sometimes filled with a species of *Isochilina* about one-fourth of an inch in length. Surfaces underlain by this formation are commonly marked by large and deep sink holes.

In thickness the Joachim limestone varies greatly. This results from erosion to which the formation was subjected prior to the deposition of the succeeding Ordovician limestones. Except in the counties bordering on the Mississippi River it is absent entirely. Where it was not wholly removed the formation ranges in thickness from a few feet to the maximum of 150 feet reported by Shumard.

The unconformity at the top is often very conspicuous. It is well shown in a long and deep cut on the Illinois Southern Railroad, about 6 miles southwest of Ste. Genevieve. Here an abruptly defined solution channel, having a depth of about 12 feet, is filled with brown and green shales, constituting the basal deposit of the overlying Plattin limestone.

THE ORE DEPOSITS.

THE STE. GENEVIEVE MINES.

History.—The Ste. Genevieve copper deposits have been described by Frank L. Nicholson.[a] According to him they were first noted in 1863, though the presence of copper in small amounts seems to have been recognized earlier at the Crow lead mines. Exploration began as early as 1868, the original discovery being followed by the opening in 1876 of the Chicago and Swansea mines and in 1879 of the Herzog. At the time of Nicholson's description the two last named were idle, while the originally discovered mine and the Chicago were being operated under the name of Cornwall mines. At present none of the properties are working.

[a] Nicholson, F. L., Review of the Ste. Genevieve copper deposits: Trans. Am. Inst. Min. Eng., vol. 10, 1882, pp. 444–456.

WORKINGS OF THE CORNWALL MINE, STE. GENEVIEVE COUNTY.

There are no data available for a complete estimate of the production, but in the Tenth Census[a] these mines are credited with an output for the census year of 230,717 pounds, valued at $25,730. As they were operated more or less actively for nearly a quarter of a century their aggregate production presumably has been considerable.

Geology.—The copper mines are situated about 8 miles southwest of the town of Ste. Genevieve, in sections 15, 16, 21, and 22 of T. 37 N., R. 8 W., along a small stream tributary to the Aux Vases River. The ore occurs principally at two horizons 125 feet apart, in the lower part of the Jefferson City limestone. The workings along the main horizon are shown in the photograph forming Pl. I. The country rock is a coarse magnesian limestone with numerous flint nodules. These are ordinarily from 2 to 4 inches in diameter, and are arranged in horizontal bands along bedding planes. They are the clear white to blue flints, such as are common in the Mississippi Valley, and do not show the druses which characterize the flints of the Gasconade formation. Certain thin and irregular sandstones are interbedded with the limestone. A very hard, quartzose bed, about 2 feet thick, occurs 15 to 20 feet beneath the main ore body at the Cornwall mines.

Faulting of some magnitude occurs in the region, and there is some evidence of faulting near, but not at the mines. The beds are practically horizontal, though there is a slight dip toward the northeast. In the general region there are outcrops of underlying pre-Cambrian crystalline rocks, though none of these are known at the mines. No other igneous rocks are found in the area. Topographically the region is a dissected plateau of some roughness.

Ore bodies.—At the Cornwall mines the ore occurs, as stated, at two horizons, of which the upper has been mainly worked. A third horizon still higher in the hill and, so far as known, not economically important, is reported by Dr. E. D. Peters. Both horizons worked are above local water level. Workings in the lower bed are mainly closed and the upper only was especially investigated. The workings extend along the edge of a horizontal bedded breccia completely around the head of the small valley in which the furnace is located. Drifts have been run into the hill at intervals, and room-and-pillar workings opened—much like those of a coal mine. No map of the workings is available for reproduction; but there are a good many hundred feet of drifts now open, and a number of excellent faces of ore may be seen.

The ore bed is from 18 inches to 3 feet thick in most parts of the mine. It seems to be thickest at the intersection of the breccia and certain small vertical fractures, along which chimneys of ore are formed, extending upward as much as 16 feet above the usual base.

[a] Tenth Census, vol. 15, p. 798.

The ore also goes down at such intersections, but seemingly not to any important extent. It consists now of a breccia of white flint, cemented mainly by chalcopyrite, but with malachite, azurite, limonite, and calcite present. Galena is reported to occur occasionally in small druses, but was not seen. Cuprite, chalcocite, tenorite, etc., occur in subordinate amounts. The cap rock and the floor of the workings consist of ordinary magnesian limestone.

An examination of the freshest specimens of the ore brings out the following details: The chalcopyrite, now very finely brecciated and in part cemented by "brown copper," is itself the matrix for fragments of white chert. This chert exists now in two forms, (1) a clear, fresh, almost glassy material, similar to the usual chert of the surrounding country, and (2) an earthy granular material known to the miners as "chalk." A microscopic examination of the latter by Mr. Lindgren shows that it is composed mainly of finely divided quartz, with some sericite. This confirms the impression, based on macroscopic examination, that it represents an alteration form of ordinary chert in which a portion of the silica has been removed by solution. Pari passu with this change has occurred the substitution of copper carbonate, and even in a single hand specimen all stages of the process can be observed, from the introduction of malachite along the cracks and the clouding of the clear chert to the complete substitution of the bright-green mineral for the sharp-angled white fragments. At the same time the brassy yellow chalcopyrite has been finely broken up and altered to the somewhat indefinite mixture known as "brown copper." It would seem, therefore, that the formation of malachite and other oxidation products marks a recent change, characterized by a tendency toward replacement of the silica. The introduction of the sulphides was evidently earlier and apparently the work of waters having other sources, since they were of such composition as to leave the chert unattacked even in small sharp-angled fragments. Presumably these sulphides replaced the dolomite in which the chert was originally bedded or were deposited in the interstices of the breccia, but as to this and the origin of the chert itself there are at present no certain data.

In the lower horizon the Revere tunnel, now partly closed, shows copper pyrites disseminated through a bed of coarse granular dolomite. There does not seem to be here any chert breccia, though the ore appears to be bedded. So small a portion of the work is open, however, that no very certain conclusions can be drawn. The bed is said to be rich, but of small extent.

Value of the deposits.—No attempt was made to sample the mine. Considerable ore is said to have been shipped, running 20 to 27 per cent in copper, and the old dump is estimated to contain 5 per cent of metal. A 16 per cent grade is said to have been commonly produced.

These claims, in the light of the appearance of the ore in the mine, do not seem extravagant. Faces of workable ore are certainly now open.

Drilling by Mr. Doak, a former owner, is reported to have shown three additional copper horizons at lower depths, and also to have shown something as to the extent of the ore body into the hill. The records of this drilling are not at hand. Dr. E. D. Peters states that 8 to 10 churn-drill holes put down under his direction several hundred feet apart and covering an area extending 1,800 feet eastward from the present workings all showed copper at the horizon of the main chert breccia. In the case of flat-lying, bedded deposits near the surface drilling is a very effective and cheap method of proving the extent of an ore body. The method is especially well suited to these deposits.

At the time the mine was working no railway was near enough to be of service, and all freight had to be hauled by wagon approximately 10 miles from the steamboat landing above Ste. Genevieve. Recently the Illinois Southern Railway has been built within 2½ miles of the mine. This line affords a direct and short route to the Illinois coal fields and materially affects the working conditions. It is quite probable that well-considered effort would result in a small, but profitable, copper industry.

MINE LA MOTTE.

This famous property includes some of the oldest mines in the United States, and up to 1893 Mr. Winslow estimates that it had produced approximately $10,000,000 worth of lead alone. In addition, copper, nickel, and cobalt occur and have been sold in quantity. At present the old copper mines are being reopened and other changes made in the operation of the property. In 1904 approximately 55 tons of metallic copper were produced in matte and ore. It is expected that in the future this product will be larger.

No extensive study of these mines was made in the course of the present investigation and no general account of the property will be given. The mines were visited, however, and the following notes are given for the sake of their bearing on the general problem of copper in this area. The history of the mines has been so completely summarized by Mr. Winslow[a] that it is not necessary to discuss it.

The mines are located in Madison County, east of the main St. Francis Mountains, and among some outlying knobs of granite and porphyry. The ore bodies are typical disseminated deposits originating by metasomatic replacement of the dolomite. They occur near the base of the Bonneterre limestone and principally in or near certain

[a] Winslow, Arthur, Lead and zinc deposits: Missouri Geol. Survey, vol. 6, 1894, pp. 267–302; vol. 7, 1894, pp. 646–659.

shaly beds in which *Lingulella* and other forms occur. Copper pyrites with sulphides of nickel and cobalt are found constantly in connection with the lead and are mainly separated at the dressing works.

In the southwestern part of the estate is a property long known as the "Copper mine" and now being reopened by the Mine La Motte Development Company, a corporation holding a lease from the main La Motte company. The copper mine is located on the flank of a small porphyry hill and the ore occurs in the Bonneterre limestone near its base. The dolomite is dark colored, shaly, and includes small porphyry pebbles. The mine was originally opened some seventy-five years ago by means of an open pit, from the back of which an adit was driven in along the bed. The old drifts had not yet been cleaned up when visited and were badly caved. In the rooms opened along this adit the sulphides were seen disseminated through approximately 10 feet of the dolomite. Galena, pyrite, and chalcopyrite occur together, thoroughly disseminated through the rock. In one part of the mine the copper pyrite, with some dark mineral, probably chalcocite, was seen segregated in a distinct bed, 3 to 10 inches thick, toward the base of the deposit as a whole, and yet above the most important bed of galena. This copper bed seems to have been the one mainly taken out when the mine was formerly worked. The galena below is largely undisturbed.

The strata throughout the mine roll slightly and irregularly, these rolls being very similar to those common in coal mines, whereby separate irregular basins are marked out. In this case the irregularities very probably reflect the irregularities of the sea bottom upon which the beds were laid down.

The occurrence of copper in this mine as a sulphide is interesting because of its intimate relations to the great disseminated lead deposits of the region. Any explanation of the genesis of the one must take into account the presence of the other, and no attempt will be made at present to discuss this large subject.

South of Fredericktown and at several other points in the vicinity copper is found.[a] None of these prospects are now open. So far as is known the occurrences are similar to that at Mine La Motte.

SHANNON COUNTY MINES.

Location.—In Shannon County there are showings of copper, and attempts have been made to mine at eight localities, which are indicated on the accompanying map (fig. 2). The largest amount of development work has been done at the Slater and so-called Jerktail properties. None of the prospects are now being developed. They are all within a few miles of Eminence, the county seat. Eminence

[a] *Keyes, C. R.*, Mine La Motte sheet: Missouri Geol. Survey, vol. 9, 1895, p. 79.

is connected by daily stage with Winona, on the Current River division of the Frisco system.

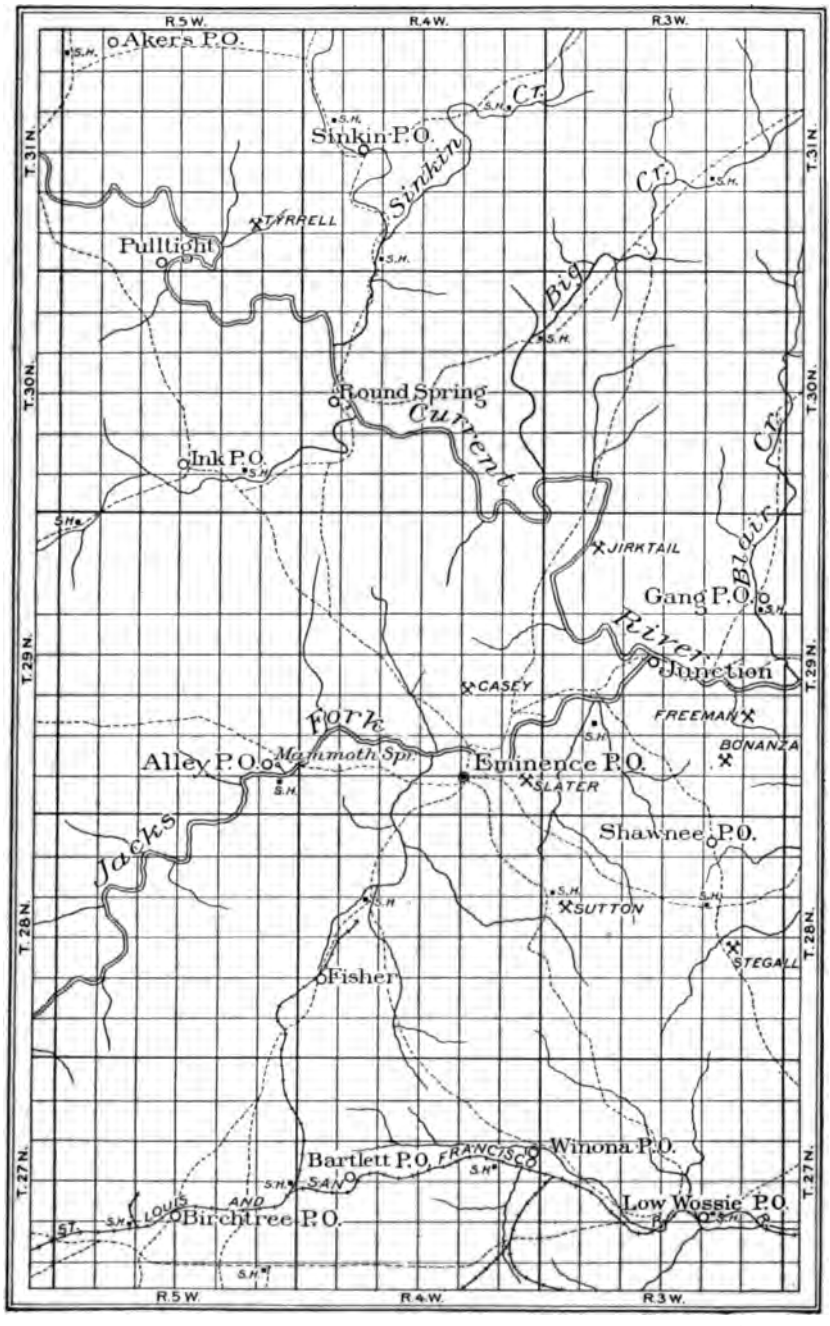

FIG. 2.—Sketch map showing occurrences of copper in Shannon County.

History.—The first attempt to regularly mine copper in Missouri seems to have been made in Shannon County some sixty-five years ago, when the Slater mine attracted attention. The following historical notes were compiled by J. H. Hahn, of Winona, Mo., and by him placed at our disposal. They represent the best obtainable information regarding this interesting property.

In 1837, when Shannon County was practically a wilderness, 150 miles from a railroad, the French settlers at Ste. Genevieve, Mo., among whom were the Valles and Henry Janis, sent Joseph Slater, an experienced miner, to develop the copper deposits of Shannon County, which locality at that time was composed largely of unsurveyed Government lands. Slater bought the possessory right of one George Smith, a hunter, who had discovered the copper; and, after erecting a small blast furnace of stone, he mined and smelted about $50,000 worth of copper.

In 1840 the lands of that locality were surveyed by the Government; whereupon a speculator by the name of John Epps Cowan preempted the land, completely ousting Slater, but not without a legal contest which was carried to the tribunal of last resort. Cowan sold the mine to other speculators in the East, who, thinking the property too remote from market to be successfully worked, closed it down.

The mine remained idle until the year 1876, when one Charles T. Biser, of St. Louis, having purchased many thousand acres of other lands in Shannon County, hunted up the owners of the mine and acquired the title to that tract. After mining and shipping a few carloads of copper, Biser sold all his holdings to the Current River Land and Cattle Company, a corporation composed of Michigan capitalists who take no interest in mining.

For twenty-five years the Slater again lay idle, when attention was called to same by F. M. Rogers, a mining prospector from Colorado. Mr. Rogers obtained a 99-year lease on the mine, which is now owned by the Slater Copper Mine Company, a corporation of Winona, Mo.

When a land survey of this area was made, the occurrence of copper was noted at a number of points and indicated upon the usual township plats. On the sectional map of the State, first published in 1865 by John T. Fiala, and revised and republished in 1881 by Campbell, the various copper localities are marked by symbols. About a half dozen are indicated in Tps. 28 and 29, Rs. 3 and 4 W. This map was compiled from all available data, and includes everything given on the Land Office map of 1811.

Bibliography.—The literature relating to the field is very limited. Below is an abstract of the important papers:

[Hodge, Jas. T., Wisconsin and Missouri lead region: Am. Jour. Sci., 1st ser., vol. 43, 1842, pp. 65–72.]

Deposits found along contact of a red porphyry with a limestone. No regular contact. Fissures between the two rocks filled with iron ore, copper ore, clay, and gossan. Little veins of copper ore in limestone. Ores are malachite, cuprite (?), and chalcopyrite. The "rotten vein" between the two rocks is a breccia of both with particles of malachite scattered through it. Ore is mined at three localities. In one the ore is more sulphide than carbonate, and the latter is partly azurite.

[Whitney, J. D., Metallic Wealth of the United States, 1854, p. 311.]

No mining worthy of name. Deposits on contact between Lower Silurian limestone and Archean quartz-porphyry. Not likely to be profitable.

[Report of the Current River Mining Company, accompanying charter and by-laws of the Current River Mining Company, of Missouri, by Stephen Bawden, mine agent, New York, 1854.]

The vein is of promising character, being composed of "gossan spar" and sulphuret of copper, green carbonates, and malachites. The lode is embedded in red granite or porphyry. The mine has a regular or true vein with a dip of 1½ feet to the fathom, running northeast-southwest. There are probably other parallel veins.

[Broadhead, G. C., Rept. Missouri Geol. Survey, 1873–74, chap. 5, p. 48.]

No copper mining now done. Mining formerly carried on in five counties. Copper ore noted in twelve others. Ores are azurite, malachite, and chalcopyrite.

[Nason, F. L., Report on iron ores: Missouri Geol. Survey, vol. 2, 1892, p. 95.]

Chalcopyrite mined to some extent near Eminence, in Shannon County. Exact locality not reported.

[Winslow, A., Geology and mineral products of Missouri: Missouri at the World's Fair [at Chicago], 1893.]

The principal occurrences of such (copper) ore are in Ste. Genevieve, Shannon, and Franklin counties. Found in magnesian limestones of Cambrian age.

[Haworth, Erasmus, Crystalline rocks of Missouri: Missouri Geol. Survey, vol. 8, 1894, p. 207.]

The porphyry in Shannon County is very similar to that northeast. Portions are the ordinary red kind. Other portions are filled with the light-gray or light-green feldspar phenocrysts, which are common to the northeast.

Slater mine.—The Slater mine is about 2 miles east of Eminence, at a point where one of the common porphyry ridges of the district projects through the Gasconade or Cambro-Ordovician dolomites. The particular knoll, on the east versant of which the copper occurs, is one of a chain extending for several miles in a northwest-southeast course. The porphyry is the usual red type so common in southeastern Missouri. It is of pre-Cambrian age. Separated from it by a marked unconformity are the gently dipping granular dolomites of the Gasconade formation. The cherty dolomites and sandstones of the Roubidoux formation occur in the higher hills surrounding the exposure.

The contact between the porphyry and the limestone is in an irregular plane, dipping at a low angle to the east. It is occupied by a well-developed conglomerate in which there are bowlders and pebbles of porphyry in a matrix of coarse crystalline dolomite. This conglomerate is not now exposed in its full thickness, but old workings are said to have shown a total of 12 feet. At the particular point at which the copper is found the surface of the porphyry dips

down, forming a shallow basin or cove, in which the conglomerate was laid down.

Copper in the form of chalcopyrite ($CuFeS_2$) and the green carbonate, malachite ($CuOH_2CO_3$), occurs in the matrix of this conglomerate. The chalcopyrite forms small, irregular crystals and grains varying in diameter from 1 millimeter to a half inch. They occur with rhombohedral crystals of dolomite of nearly uniform size and grains of quartz in a paste of greenish clay. The carbonate is found in similar disseminated grains, apparently the altered remnants of chalcopyrite, and also in flecks and thin seams penetrating and replacing the porphyry fragments. At the surface, where the rock has been exposed, the cracks and crevices contain a black, sooty powder, apparently mainly manganese oxide, bearing copper probably in the form of the oxide or of chalcocite (Cu_2S). An assay of this material in the Survey laboratory, by George Steiger, gave 6.44 per cent copper.

The largest amount of work done on the property has evidently been in the stripping and mining of this conglomerate over some 3 acres. To the east, where the rock dips under cover, it has not been followed. Along the strike less prominent copper showings are said to occur at intervals for nearly 2 miles.

Copper also occurs in the porphyry, and several shafts have been sunk, following small veins into this rock. One of these shafts is reported to be 160 feet deep. This was filled with water at the time the property was examined. The rock on the dump showed thin seams in the porphyry, and in these small crystals of quartz, dolomite, and chalcopyrite occur. In no specimen seen was the amount of the latter sufficient to make the rock workable. In other pits not so deep similar crevices in the porphyry were seen filled with the green carbonate. This occurred at one place as much as 4 inches thick and practically free from admixture with other minerals. All the crevices examined were small, an inch or two in width at most, and all have a general northwest-southeast course, parallel to the general trend of the porphyry hill. They are not larger, more numerous, or, except for their content of copper, more impressive than at many other points in the porphyry of the region. Several of the earlier observers have mentioned "true fissure veins" as occurring in the porphyry, but so far as observations of the present writers go these minor crevices are the only foundation for such statements.

The prospective value of the property is so intimately connected with the probable genesis of the ores that it is necessary to consider at least the possible character of the latter.

The chalcopyrite is not apparently present in quantities of economic importance; the question of the origin of the sulphides is *therefore* relatively unimportant. It is believed that they were

derived from the porphyry by leaching either (1) of minutely disseminated quantities of copper, known to be present in the rock, or (2) of small veins locally present, of which the ores now exposed are representatives. This is believed to have occurred at the time the conglomerate was formed, though it is quite possible that the process continued in operation through later geologic ages.

The carbonates, oxides, and possible chalcocite present are alteration products from the sulphides, and the topographic and structural features of the deposits indicate clearly that this alteration has been accompanied by at least some concentration. The open, porous conglomerate affords abundant opportunity for the circulation of waters, while the decomposition of the lime-soda feldspars of the porphyry fragments would serve to precipitate as carbonate any copper sulphate present. It is notable that the decomposed porphyry pebbles and the carbonate are closely associated. In any such process the carbonates would be carried down, more or less, and precipitated in the upper fissured part of the porphyry below, and this is believed to have been the origin of the carbonate found in that situation.

It follows from the above considerations that future prospecting should be directed toward finding extensions of the conglomerate and points of local enrichment rather than toward following the small veins into the underlying porphyry. The cove in which the deposits occur opens out to the east, in which direction also the rocks dip. A series of drill holes parallel to the outcropping edge of the conglomerate should determine the depth and extent of mineralization very cheaply.

Jerktail mine.—This is one of the older and better-known prospects. It is said to have been worked about 1840 and again in 1870, and shipments have been made from the property. There has been some recent prospecting. There are several shallow shafts and one drift. The conditions are very similar to those at the Slater mine. The Gasconade limestone rests on the porphyry with gently sloping contact, and the usual conglomerate is present. In this conglomerate both chalcopyrite and malachite occur, and there has evidently been some reconcentration of material. There is the same pre-Cambrian erosion basin or cove, in this case fronting to the southwest rather than east, and the geologic and topographic features of the two localities are almost identical. One exception is that present exposures at least do not show small veins running down into the porphyry, as observed at the Slater mine. There are no sufficient data for estimating the probable size and value of the deposit.

Sutton mine.—This property, 5 miles southeast of Eminence, resembles the Slater and Jerktail, in that copper carbonate is found in the base of the limestone at the contact with the underlying porphyry.

There are no recent openings, and the details of the occurrence are not so well displayed as at the other mines mentioned, but the phenomena seem to be essentially the same.

Casey mine.—About 2 miles north of Eminence, in a saddle between high flint-capped hills, copper has been found in the limestone and away from any immediate contact with porphyry. The horizon is in either the basal portion of the Roubidoux or near the top of the Gasconade limestone, and is thus considerably above that of the copper at the Slater mine. The country rock is a coarse, granular dolomite, in which is a bed of shale 4 to 12 inches in thickness. In this shale, and at points completely replacing it, is copper, mainly in the form of malachite, but also occurring as chalcocite. The bed has been followed into the hill by means of an adit some 50 feet. A few years ago the property came into the hands of certain Pittsburg people, who abandoned the drift and began sinking. It is said that they have discovered a second, but seemingly less extensive, copper horizon below the ore worked in the drift.

The rocks are horizontal, bedded limestones, with no signs of faulting or of vein phenomena. There are no outcrops of porphyry in the immediate vicinity. The origin of the copper is somewhat more difficult of explanation than at the Slater mine. It can only be said that copper-bearing solutions have evidently circulated somewhat extensively through the rocks of the region, and that the shale band has afforded a favorable horizon for its lodgment, either by direct reduction through the action of organic matter or by the mechanical process recently described as adsorption.

The extent of the deposits is unknown, owing to the way the prospecting has been carried on. They do not seem likely to be large.

Tyrell mine.—At this property, which was visited by Mr. Ellis, the copper occurs in the form of chalcocite and malachite in a brecciated dolomite, resembling in hand specimens some of the material found at Ste. Genevieve. So far, however, flats have not been developed, all the ore mined having come from a small vertical seam running northwest-southeast. This has been followed down 48 feet, and is said to have shown some copper the whole distance. The slope above the prospect is covered with chert and sandstone, probably betokening the presence of the Roubidoux, so that the horizon is probably about the same as at the Casey mine.

Bonanza prospect.—Situated about 6 miles east of Eminence, this is instanced as typical of a number of small prospects scattered throughout the county. Not far from a porphyry outcrop, but in the limestone hill above it, a few small pits have been sunk. Apparently they merely reached the solid rock. No copper minerals of any kind are now shown on the dumps. A green mineral in small flakes, probably chlorite, has apparently been mistaken for malachite.

In the porphyry at the foot of the hill are some thin streaks of white quartz, and at the contact of the porphyry and the limestone a black earthy material is found in small quantity. This not improbably contains some chalcocite, since it is said to show on assay 4 per cent of copper and 1 ounce of silver per ton.

Freeman prospect.—This is very similar to the Bonanza. Copper carbonate and galena are said to have been found in small quantity in shallow pits in the limestone. At present nothing but ordinary limonite and residual clay are exposed.

General conclusions.—From the descriptions already given of the individual prospects it will be evident that there is small probability of true vein deposits of value being found in the porphyry. The largest amounts of copper are in the limestone, and of the two horizons recognized the lower is the more favorable. Along this, where the structural and topographic conditions have been favorable, copper occurs in the conglomerate. The deposits are thus essentially blanket veins, and in view of their shallow dip they may be most easily prospected by drilling and test pitting. Such ore as occurs is of a nature to be easily reduced, and the samples seen are evidently of good grade. The size of the ore bodies can be determined only by additional prospecting.

THE SULLIVAN MINES.

History.—On the northeast flank of the Ozark uplift, in Franklin, Crawford, Phelps, and adjacent counties, copper minerals have been found at a number of points, and several attempts have been made to develop mines. Recently some prospecting has been carried on near St. James, Phelps County, and the Missouri Copper Mountain Mining Company has put in operation a 20-ton furnace near Sullivan, on the Frisco system. This corporation, composed largely of persons living at Sedalia, Mo., owns nearly 7,500 acres of land in Washington and Crawford counties. Development has been under way for nearly three years, an attempt having first been made to concentrate and ship the ores and later a furnace having been built and put in operation. The works are located in sec. 24, T. 40 N., R. 2 W., in Crawford County. They are at the old Sullivan and Bridell mine, where the Hamilton Iron Company, up to 1873, took out specular iron ore.

Geology.—The area in which the copper has been found is that known in the older geologic reports as the region of the "Second sandstone." Nason used "Roubidoux sandstone" to designate the surface rock of the district, and applied Gasconade limestone[a] to the heavy limestone beds found in the lower portions of the valleys.

[a] Nason, F. L., Report on iron ores: Missouri Geol. Survey, vol. 2, 1892, p. 114.

The ore is found in residual clays, filling pits in the Gasconade limestone and near the outcropping edge of the overlying Roubidoux.

The copper occurs in connection with or near to the specular iron-ore deposits which characterize the district. These iron deposits have been described by Nason,[a] who considered them to represent concentrations made by surface waters in sink holes. He noted the common association with the hematite of sulphides of iron, copper, lead, zinc, and arsenic, and the fact that these sulphides occur most abundantly at the bottom of the deposits. Indeed, he considered the iron to have been originally concentrated as a sulphide, and to have been later altered to hematite. This theory of the origin of the ores would make them strikingly analogous to the iron cappings, or gossan, over mixed sulphide ore bodies, such as occur in the Western States.

In 1904 a number of the old iron pits of this area were reexamined and Nason's observations were confirmed. It was found very commonly that sulphides and carbonates of copper, in particular, occur in intimate mixture with the hematite at the bottom of the now abandoned pits. How important in amount this ore may be was not determined, but its widespread occurrence was very evident and its position is believed to be significant.

Ore bodies.—The copper mined at Sullivan is obtained from shallow workings on the side of a hill, near the top of which iron was formerly mined. The old iron pits are now partially filled by surface wash. The ore body was evidently of the usual irregular form, and the ore now remaining in the bottom of the pit and in the short drifts running back into the hill is low grade and siliceous. The dump shows the usual red hematite and ocher. Copper is reported to have been found in the lowest part of the old workings, but none is now exposed.

Lower on the slope are the shafts recently sunk in search of copper. The dumps around these shafts show red hematite, broken and brecciated, and with thin flakes and seams of copper carbonate running through it. The surface is mainly covered with red clay and chert fragments, though limestone and sandstone are also present. On the dumps are pieces of a dark-colored limestone which shows veins of calcite one-sixteenth to one-eighth inch thick, with similar but still thinner veins of pyrite, which also occurs in very fine-grained, irregular particles through the rock. Portions of the limestone have been altered to a brown, vitreous, porous rock, greatly resembling garnet in appearance. Under the microscope it is seen to be now composed almost wholly of crystalline quartz with occasional small aggregates of malachite. Running through the quartz, without re-

[a] Nason, F. L., Report on iron ores: Missouri Geol. Survey, vol. 2, 1892, pp. 116–157.

gard to the crystal boundaries, are irregular convoluted bands of brown iron oxide. Apparently these outline the grains of the original limestone, now wholly replaced by silica.

The main workings are below these shafts, the entrance being by adit connected with one of them. The adit is cut through a bar of limestone, beyond which is a body of soft red clay, in which the copper occurs. Both chalcopyrite and the usual alteration products occur, irregularly distributed through the clay. Balls of the chalcopyrite a half foot or more in diameter and coated with malachite and chalcocite are found. Not enough work has yet been done to develop the form of the ore body, but it is known to be somewhat irregular. Both lead and zinc ores occur on the same land, though neither were seen in the copper workings.

It would seem that the copper occurs in a residual clay occupying an irregular pit in the limestone of the hillside. It is above water level and below the main body of iron ore. It was originally in the form of a sulphide, and the present ore has resulted in part from concentration in situ by residual action. Probably also copper has been leached out of the higher portion of the hill, the iron being left behind as a gossan. Accompanying this action there has been at least local silicification of the limestone. The original introduction of the sulphides was by waters which were of different composition, since for a long time the waters of the region have been destroying rather than building up the sulphides. The nature and source of these waters are for the present uncertain. So far as known, the original sulphides are not sufficiently rich to be worked alone for copper, and only the pockets found in the coves of residual reconcentration warrant prospecting.

Value of the deposits.—No general sampling of the mine was attempted. An average sample of the face of one drift, as nearly as it could be taken, was found, on assay in the Survey laboratory by George Steiger, to carry 12.55 per cent of copper. It is impossible to say what the average of the whole ore body would run. It is estimated by H. H. Graham, manager of the property, that the ore going to the furnace runs 5 to 8 per cent. From a twenty-day run in 1904 30,000 pounds of pig copper and matte resulted. This is equivalent to 22,500 pounds of metallic copper. According to the records of W. H. H. Myers, secretary of the company, the ore used in the furnace during this run averaged 14 per cent. The ore is practically self-fluxing and easily and cheaply handled. So long as no greater difficulties than those now apparent arise, it should be possible to work this ore profitably. In view, however, of the very great irregularities in form and richness characteristic of residual ores, it is impossible to make any valid estimates for the future.

GENERAL SUMMARY AND CONCLUSIONS.

Copper in the form of sulphides and carbonates has been found at many points in southern Missouri and has been mined in several localities, notably in Ste. Genevieve, Madison, Shannon, and Crawford counties. Very large deposits, rivaling those of the West, have not been found and are not to be expected. The character of the ore and the low cost of flux, fuel, and labor make it possible to work some, at least, of the deposits with profit.

The ores show a preference for certain stratigraphic horizons, and, being bedded, may be prospected with ease and economy. The common association of sulphides with specular iron of the sandstone region points to the advisability of the investigation of the old iron pits. While any copper deposits found will probably not be large, they should be easily and cheaply mined. In Shannon County the most favorable localities are along the contact of porphyry and dolomite at points where the conglomerate beds at the base of the latter fill in shallow basins in the crystalline rocks. In the disseminated lead district of southeastern Missouri copper occurs in connection with the lead, and at a few points can be saved to advantage.

The ores were doubtless formed by concentration of material originally disseminated in the surrounding rocks. Winslow and Robertson[a] some time since proved that both the crystalline rocks and the dolomites of this region contain copper in minute but sufficient amounts. The preference of the ore bodies for certain horizons is believed to be dependent mainly upon original unequal distribution of material resulting from land and sea conditions at the time the rocks were laid down. Excepting the Mine La Motte deposits, all the important copper deposits of Missouri are found in that part of the Potosi rocks which was laid down in shallow waters and when frequent changes of shore line were evidently occurring. The Ste. Genevieve deposit occurs in brecciated horizontal chert in the lower part of the Jefferson City limestone; the Sullivan deposit has been segregated from beds near, probably just beneath, the Roubidoux sandstone; and in the Casey mine the ore is found in the Roubidoux. The Slater, Jerktail, and Sutton mines, in Shannon County, occur along the contact between old porphyry islands and the dolomites of the Gasconade formation. The Mine La Motte ores occur where the similar Bonneterre limestone laps upon similar porphyry hills. Everywhere the distribution of the copper seems related to original shallow-water conditions. At some later period in the course of the work of underground waters this originally disseminated copper was segregated in the bodies now found.

[a] Winslow, Arthur, and Robertson, J. D., Lead and zinc deposits: Missouri Geol. Survey, *vol. 7, 1894*, pp. 479–489.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

MIOCENE FORAMINIFERA FROM THE MONTEREY SHALE OF CALIFORNIA

WITH A

FEW SPECIES FROM THE TEJON FORMATION

BY

RUFUS M. BAGG, JR.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., May 12, 1905.

SIR: I transmit herewith the manuscript of a report on "Miocene Foraminifera from the Monterey Shale of California, with a Few Species from the Tejon Formation," by Dr. Rufus M. Bagg, jr., with an introduction by Prof. J. C. Branner, and recommend that it be published as a bulletin of the Survey.

Very respectfully,

C. W. HAYES,
Geologist in Charge of Geology.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

MIOCENE FORAMINIFERA FROM THE MONTEREY SHALE, CALIFORNIA, WITH A FEW SPECIES FROM THE TEJON FORMATION.

By Rufus M. Bagg, Jr.

GEOLOGY.

By J. C. Branner.

The Miocene Foraminifera described in this bulletin were collected by me from the Monterey shale, on the Rancho del Encinal, near Asuncion station, in San Luis Obispo County, Cal. The exposure from which the material was taken is in the bed of Graves Creek, about 500 feet south of J. H. Henry's ranch house, and 7,000 feet nearly due south of Asuncion station, on the coast division of the Southern Pacific Railway. The same, or similar, fossiliferous beds are exposed at many places in the hills and gulches northwest of Mr. Henry's house.

The accompanying map and section on the line A–B (figs. 1 and 2) show the general geology of the neighborhood well enough for present purposes.

The Monterey shale is between 2,000 and 2,500 feet thick here, and forms one broad fold, though there are many small faults that are not indicated on the section, and considerable variations in the direction and amount of the dips. In places the beds are much wrinkled. The shale series is not uniform throughout, but contains layers that are more or less sandy. On Graves Creek, between its mouth and the ranch house, there are several exposures of a bed of coarse sandstone interbedded with the shale that is at least 10 feet thick. The shale proper also varies: at some places it is flinty, at others it is somewhat sandy, and at still others it is soft and chocolate-colored, and contains an abundance of well-preserved Foraminifera. At one place, about 1,500 feet below the ranch house, I found in the creek bed an undetermined vertebrate fossil about 4 feet long. This is the only fossil observed in these rocks beside the Foraminifera and diatoms. The

bulk of this shale is made of diatom skeletons. In some places the rocks are soft and powdery enough to be used for polishing powder. In color the shale varies from white through cream colored and gray

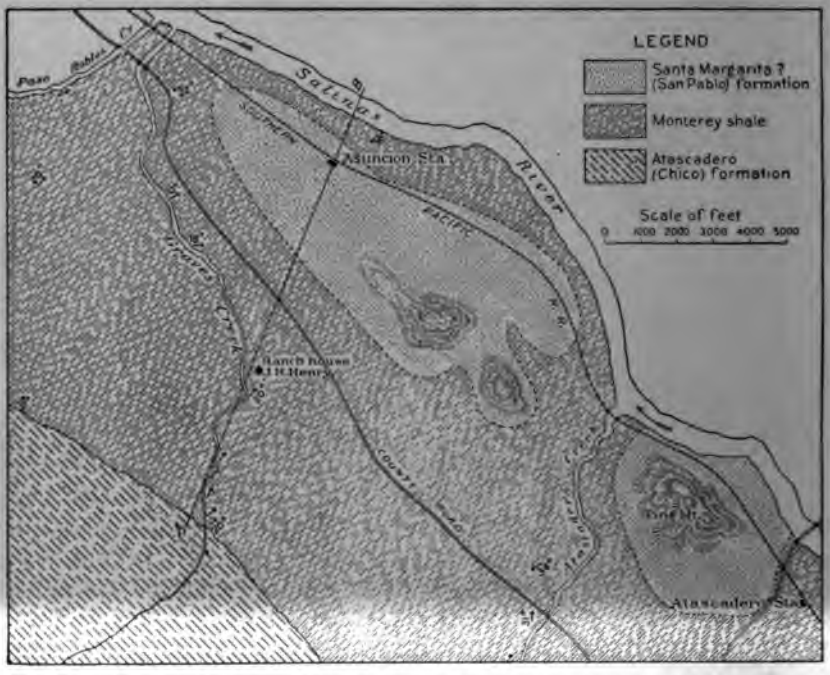

FIG. 1.—Geologic sketch map of a portion of San Luis Obispo County, Cal.

to amber colored and black. Even when the rocks are flinty they often contain good impressions of Foraminifera.

The Monterey shale is exposed at many places along Atascadero Creek, and nearly everywhere in this vicinity it contains Foraminif-

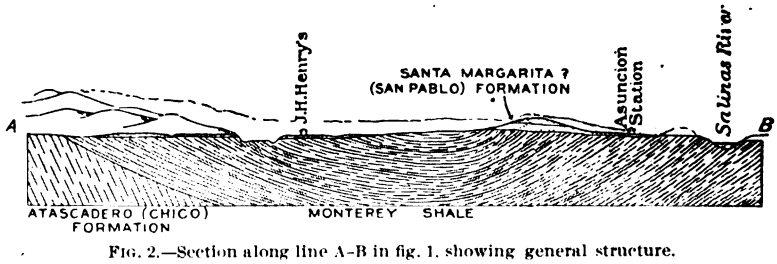

FIG. 2.—Section along line A-B in fig. 1, showing general structure.

era, though most of the rocks are too hard to allow them to be taken out.

It is of interest to note that nearly all of the Monterey shale in this neighborhood contains a notable amount of hydrocarbon—enough, at least, to cause it to burn with a flame when placed in a hot fire. I have had the hydrocarbons determined in two typical samples of the shale.

SANDSTONE INTRUSION IN MONTEREY SHALE ON GRAVES CREEK, 1 000 FEET SOUTH OF J. H. HENRY'S RANCH HOUSE.

One kind—the hard, amber-colored chert from Atascadero Creek and from just south of Havel station on the railway—yielded 12.8 ounces of oil to the ton of rock. The chocolate-colored, soft shale that contains so many Foraminifera was found to contain 102.4 ounces, or about 0.86 gallon of oil, to the ton of rock. The specimens examined in both cases came from the surface, and it is quite possible that under cover the rocks contain a little more oil.

A matter of considerable interest in connection with this shale is that it is traversed at several places along Graves Creek above the ranch house by sandstone intrusions or dikes that appear to have come from below. (See Pl. I.) They vary in thickness from less than an inch to several feet. These dikes are described by Prof. J. F. Newsom in the Bulletin of the Geological Society of America, vol. 14, page 227.

The Monterey shale in this region rests upon a series of snuff-colored sandstones which a little farther south, in the San Luis Obispo quadrangle, are referred by Fairbanks to the Atascadero (Chico). It is overlain by a series of coarse sands and gravels that form the low hills lying between Mr. Henry's ranch house and Asuncion station, and forming also Pine Ridge, the hill just west of Atascadero station. These overlying beds are regarded by Doctor Fairbanks as Santa Margarita (San Pablo), or upper Miocene. I am inclined to believe that they are Pliocene. Their age is of no especial importance in the present discussion, however, further than that they are clearly not a part of the Monterey shale.

GENERAL RELATIONS.

The writer's study of the fossils of the Miocene clay marl of Graves Creek, San Luis Obispo County, Cal., collected by Prof. J. C. Branner, has yielded an interesting fauna of sixty-six species, including a few varieties, and seventeen genera. These genera are *Bulimina*, *Bolivina*, *Lagena*, *Nodosaria*, *Cristellaria*, *Uvigerina*, *Sagrina*, *Globigerina*, *Orbulina*, *Pullenia*, *Discorbina*, *Truncatulina*, *Anomalina*, *Pulvinulina*, *Rotalia*, *Nonionina*, and *Polystomella*.

A glance at the list (pp. 13–15) reveals the absence of arenaceous genera and species, of warm-water Miliolidæ, the presence of but one member of the Nummulitic group, and the large number of rotaline types. The absence of the arenaceous genera undoubtedly shows the purity of the waters in oceanic circulation during the Miocene, and this evidence is still further substantiated by the fine argillaceous and silt character of the deposit in which the Foraminifera are deposited. The Foraminifera, in fact, constitute a large portion of the entire mass of the marl itself, while sand and coarse pebbles are practically absent. Only in one instance was a pebble detected in the material washed. This pebble is upward of half an inch in diameter and is composed of dark flinty quartz. The majority of the mass in which

the fossils are embedded is rich in aluminum and occasionally there are calcareous nodules and irregular-shaped fragments which when dissolved in hydrochloric acid leave a small deposit highly aluminous. No phosphates were detected in these calcareous masses.

The majority of forms identified are present in abundance to-day in the North Atlantic Ocean (see list, pp. 13–15), and the writer is confident that the conditions there to-day represent pretty well the oceanic temperatures and depths at which the California beds were laid down. These fossils were presumably deposited in waters the depth of which was less than 500 fathoms. Forms like *Globigerina bulloides* and *Orbulina universa* are, of course, surface types and are untrustworthy guides when the fauna as a whole is considered. The relative abundance of forms of any one species is an important indication of the conditions under which a given formation was laid down. The occurrence in relative abundance of forms found only in shallow waters, such as *Bolivina ænariensis*, *Bolivina textilarioides*, *Bulimina elegantissima*, *Discorbina allomorphinioides*, *Nodosaria filiformis*, *Pulvinulina auricula*, and *Uvigerina tenuistriata*, afford ample evidence that the entire fauna was deposited in shoal waters.

The fauna as a whole is remarkably similar to that of the older Pliocene beds of Monte Bartolomeo described by Egger in 1895.[a] This fact has already been pointed out by Chapman in his report on the California Foraminifera.[b] The foraminiferal contents of the Miocene beds examined by the writer and described in the Bulletin of American Paleontology[c] have only a general resemblance to the fossils under discussion and are not as closely related as those of the middle Tertiary beds in Europe.

The foraminiferal shells in this gray-brown marl are peculiar in that their chambers are rarely filled with the exogenous matter composing the matrix in which they are deposited. They will therefore float readily on water, which is of assistance in separating them from the matrix. This fact is also of importance as indicating the rapidity with which the Miocene beds were deposited, since in nearly all cases of fossil Foraminifera with which the writer is familiar the shells are filled more or less completely with the material in which they are embedded.

The only report on the California Miocene of which the author has any knowledge is one by Mr. Frederick Chapman, entitled "Foraminifera from the Tertiary of California," published in the Proceedings of the California Academy of Sciences, 3d series, vol. 1, No. 8, 1900 (San Francisco). Of the species identified and described in this report

[a] Fossile Foraminiferen von Monte Bartolomeo am Gardasee: Jahrsber. Naturhist. Ver. Passau, vol. 16, 1895.

[b] Foraminifera from the Tertiary of California: Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, 1900.

[c] Tertiary and Pleistocene Foraminifera of the middle Atlantic slope: Bull. American Paleont., vol. 2, No. 10.

by Mr. Chapman, many were found also in the material investigated by myself, and in addition many new forms were recognized. The new Cristellarian described by Chapman under the name of *Cristellaria miocenica* was not recognized although Mr. Chapman found the fossil in abundance in his material. Mr. Chapman's material is described as a close-textured, gray-brown marl from the Tertiary marl of California marked "Miocene?" and a second specimen was from a well boring in Santa Clara County similar to the first, somewhat paler, and rather shaly. The matrix when seen in thin section Chapman describes as consisting of basaltic or palagonitic material crowded with hollow-chambered Foraminifera. From this description it appears probable that Mr. Chapman's specimens were from the same formation as the material examined by the author of this report.

Before describing the species it is perhaps best to state that the references and synonyms given under each species are not complete, only the more important and accessible references being included and in every case the original description being placed first.

Again, in one or two reports the author has been obliged to use the paging given in reprints, especially in the report of Johann Egger, previously referred to, and he does not feel positive that the pages given will correspond with what may be later found in the bound volumes, of which these abstracts are a part. The plate numbers and figures and other reference matter should be found without error.

Table showing limits of depth of existing representatives of the fossil Foraminifera found in the Miocene of California.

Name.	Depth.	Chief locality.
Anomalina ammonoides	To 1,350 fathoms	South Pacific.
Anomalina ariminensis	150 to 2,200 fathoms	North Atlantic.
Anomalina grosserugosa	345 to 2,160 fathoms	North and South Atlantic.
Anomalina rotula	Not known outside Tertiary.	
Bolivina æenariensis	Shallow waters	North Atlantic.
Bolivina dilatata	To 1,180 fathoms	Do.
Bolivina dilatata var. angusta	do	Do.
Bolivina punctata	All depths	All oceans.
Bolivina punctata var. substriata.	do	Do.
Bolivina textilarioides	Shoal waters	Wide area.
Bulimina affinis	Deep, one Cuba	North Pacific.
Bulimina buchiana	Fairly deep water	North Atlantic.
Bulimina elegans	Depths not known	Wide range.
Bulimina elegantissima	Very shoal water	Do.
Bulimina elongata	630 North Atlantic, 1,425 South Atlantic.	North and South Atlantic.

Table showing limits of depth of existing representatives of the fossil Foraminifera found in the Miocene of California—Continued.

Name.	Depth.	Chief locality.
Bulimina ovata	South Atlantic, 2,200; South Pacific, 15 to 580; North Atlantic, shallow to 1,400.	
Bulimina pupoides	Shoal to 100 fathoms	Wide area.
Cristellaria articulata	Less than 400	
Cristellaria cassis	Shallow water	Adriatic and Mediterranean.
Cristellaria crepidula	Shoal water, one example, 2,350 fathoms.	Wide.
Cristellaria crepidula var. gladius.	Found in Tejon formation.	
Cristellaria gerlandi	Miocene only	
Cristellaria gibba	Less than 500 fathoms	Rare to-day.
Cristellaria rotulata	To 2,000 fathoms	All oceans.
Discorbina allomorphinoides.	10 to 155 fathoms	Three localities only.
Globigerina bilobata	Bottom ooze, various depths	Wide range.
Globigerina bulloides	All depths	Universal area.
Globigerina cretacea	Fossil	
Globigerina dubia	Bottom ooze	Very limited distribution to-day.
Lagena apiculata	All depths to 3,000 fathoms	Every latitude.
Lagena globosa	All depths	All oceans.
Lagena gracilis	Usually shallow water, rarely to 2,775.	Wide area.
Lagena marginata	All depths to 3,125 fathoms	All latitudes.
Lagena sulcata	To 2,750 fathoms typically shoal water.	Wide range.
Nodosaria adolphina	Doubtfully recent	
Nodosaria communis	All depths	Every latitude.
Nodosaria consobrina	129 to 1,375, mostly moderate.	South Atlantic and South Pacific.
Nodosaria consobrina var. emaciata.	....do	Do.
Nodosaria farcimen	All depths	Every ocean.
Nodosaria filiformis	To 500 fathoms	Not widely distributed.
Nodosaria obliqua	To 200 fathoms	Every ocean.
Nodosaria pauperata	All depths	Do.
Nodosaria radicula	Shore waters to 2,350 fathoms.	Not in North Pacific.
Nodosaria roemeri	Less than 400 fathoms	Mostly in North Atlantic.
Nodosaria soluta	125 to 1,360 fathoms	North and South Atlantic and South Pacific.
Nonionina boueana	Few to 200 fathoms	Only few places now, North Atlantic.

Table showing limits of depth of existing representatives of the fossil Foraminifera found in the Miocene of California—Continued.

Name.	Depth.	Chief locality.
Nonionina communis	Presumably fossil only	
Nonionina pompilioides	Deep water only, 1,000 to 3,000 fathoms.	Southern and northern oceans.
Nonionina umbilicatula	30 to 3,125 fathoms	Widely distributed.
Orbulina universa	All depths	Every ocean.
Polystomella crispa	To 355 fathoms	Arctic and tropical waters.
Pullenia sphæroides	To 3,000 fathoms	All oceans.
Pulvinulina auricula	Shoal waters in North Atlantic known to 500 fathoms.	
Pulvinulina brongniartii		Adriatic only so far as known.
Rotalia beccarii		Inhabits margins of all great oceans.
Rotalia soldanii	Deep waters never less than 300 fathoms.	Wide area.
Sagrina branneri	Miocene only	
Sagrina californiensis	do	
Sagrina elongata	do	
Truncatulina lobatula	Every ocean	All depths.
Truncatulina pygmæa	Deep water	Considered rare.
Truncatulina variabilis	Shallow water (only one example, 2,000 fathoms).	Wide area.
Truncatulina wuellerstorfi	200 to 2,000 fathoms	Do.
Uvigerina canariensis	Shore sands to 1,900 fathoms.	South Pacific and South Atlantic, etc.
Uvigerina pygmæa	2 to 2,500 fathoms	North Atlantic, common; universal also.
Uvigerina tenuistriata	Shallow waters	Many localities.

LIST OF SPECIES DESCRIBED (SYSTEMATICALLY ARRANGED).

Family TEXTULARIDÆ.

Subfamily BULIMINÆ.

Bulimina affinis d'Orbigny.
buchiana d'Orbigny.
elegans d'Orbigny.
elegantissima d'Orbigny.
elongata d'Orbigny.
ovata d'Orbigny.
pupoides d'Orbigny.

DIMORPHOUS FORM.

Bolivina æenariensis (Costa).
dilatata Reuss.
dilatata var. angusta Egger.
punctata d'Orbigny.
punctata var. substriata Egger.
textilarioides Reuss.

Family LAGENIDÆ.

Subfamily LAGENINÆ.

Lagena apiculata Reuss.
globosa (Montagu).
gracilis Williamson.
marginata (Walker and Boys).
sulcata (Walker and Jacob).

Subfamily NODOSARINÆ.

Nodosaria adolphina d'Orbigny.
communis (d'Orbigny).
consobrina d'Orbigny.
consobrina var. emaciata Reuss.
farcimen (Soldani).
filiformis (d'Orbigny).
obliqua (Linné).
pauperata (d'Orbigny).
radicula (Linné).
roemeri (Neugeboren).
soluta (Reuss).
Cristellaria articulata (Reuss).
cassis (Fichtel and Moll).
crepidula (Fichtel and Moll).
crepidula var. gladius Philippi.
(Robulina) gerlandi Andreae.
gibba d'Orbigny.
rotulata (Lamarck).

Subfamily POLYMORPHINÆ.

DIMORPHOUS FORM.

Uvigerina canariensis d'Orbigny.
pygmæa d'Orbigny.
tenuistriata Reuss.
Sagrina branneri Bagg.
californiensis Bagg.
elongata Bagg.

Family GLOBIGERINIDÆ.

Globigerina bilobata d'Orbigny.
bulloides d'Orbigny.
cretacea d'Orbigny.
dubia Egger.
Orbulina universa d'Orbigny.
Pullenia sphæroides (d'Orbigny).

Family ROTALIDÆ.

Subfamily ROTALINÆ.

Discorbina allomorphinoides (Reuss).
Truncatulina lobatula (Walker and Jacob).
pygmæa Hantken.
variabilis d'Orbigny.
wuellerstorfi (Schwager).
Anomalina ammonoides (Reuss).
ariminensis (d'Orbigny).
grosserugosa (Gümbel).
rotula d'Orbigny.
Pulvinulina auricula (Fichtel and Moll).
brongniartii (d'Orbigny).
Rotalia beccarii (Linné).
soldanii (d'Orbigny.)

Family NUMMULINIDÆ.

Subfamily POLYSTOMELLINÆ.

Nonionina boueana d'Orbigny.
communis d'Orbigny.
pompilioides (Fichtel and Moll).
umbilicatula (Montagu).
Polystomella crispa (Linné).

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N. B.—Only the more important reports are given in this bibliographic list. A fuller account of American papers in which reference to Foraminifera is made is found in the author's preceding papers referred to in the above list.

DESCRIPTIONS OF THE SPECIES.

Family TEXTULARIDÆ.

Subfamily BULIMINÆ.

Genus BULIMINA d'Orbigny (1826).

BULIMINA AFFINIS d'Orbigny.

Pl. II, fig. 1

Bulimina affinis d'Orbigny, 1839, De la Sagra, Hist. Physiq., etc., de Cuba, Foraminifères, p. 105, pl. ii, figs. 25, 26.

Bulimina ovulum Reuss, 1850, Haidinger's Naturw. Abhandl., vol. 4, p. 38, pl. iv, fig. 9.

Bulimina affinis Brady, 1884, Challenger Report, vol. 9, pp. 400, 401, pl. l, figs. 14a, b.

Bulimina affinis Sherborn and Chapman, 1886, Jour. Roy. Microsc. Soc., ser. 2, vol. 6, p. 743, pl. xvi, fig. 1.

Bulimina affinis Egger, 1895, Jahrsber. Naturhist. Ver. Passau, vol. 16, pp. 14, 15, pl. iv, figs. 4, 5.

Bulimina affinis Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 244, pl. xxix, fig. 4.

Bulimina affinis in its ovate character and few chambers resembles *B. ovata* d'Orbigny and *B. pupoides* d'Orbigny. The arrangement of chambers in *B. affinis* is, however, more tapering at the distal end, while *B. pupoides* has shorter segments. The species occurs frequently in the California Miocene. Its geological range is very extensive, as it is found in the lower Greensand of the English Cretaceous. At the present time it is found in the North Pacific and west of Patagonia. D'Orbigny's single specimen came from the shore sands of Cuba.

BULIMINA BUCHIANA d'Orbigny.

Pl. II, fig. 2.

Bulimina buchiana d'Orbigny, 1846, Foram. Foss. Vienne, p. 186, pl. xi, figs. 15–18.

Bulimina buchiana Carpenter, Parker, and Jones, 1862, Introd. Study Foram., pl. xii, fig. 19.

Bulimina buchiana Brady, 1884, Challenger Report, vol. 9, pp. 407, 408, pl. li, figs. 18, 19.

Bulimina buchiana Bagg, 1898, Bull. American Paleont., vol. 11, No. 10, pp. 315, 316, pl. xxii (2), fig. 4.

Bulimina buchiana Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, pp. 244, 245, pl. xxix, fig. 5.

Test short and stout, triserial, tapering; posterior end acutely rounded, anterior, obtuse; segments distinct, slightly inflated; surface of shell marked by definite longitudinal costæ, which extend with varying lengths two-thirds or less upward from initial chamber. In typical forms these reach to within one-third the end of the final segment.

The length and size of this species are variable, but the stoutly built form and surface decoration serve to identify it. Sometimes, as in the California specimens, the striæ are so delicate as only to be visible in reflected light, while again, as in the specimens the author found in well borings at Norfolk, Va., they are large, deep, and remarkably sharp.

The geological range of the species is from Eocene to Recent.

Prof. H. B. Brady remarks that this species inhabits fairly deep water, and further adds that while it is abundant in the North Atlantic it has not been found in the North Pacific. He considers that *Bulimina inflata* and *Bulimina rostrata* are closely related to the present species. Compared with the present form, *Bulimina inflata* is of similar size, but the costæ are short and are extended beyond the margin of the chambers in the form of spines; *Bulimina rostrata* is smaller, has indistinct segmentation, and the costæ cover the entire shell.

Bulimina elegans d'Orbigny.

Pl. II, fig. 3.

Bulimina elegans d'Orbigny, 1826, Annales Sciences Naturelles, vol. 7, p. 270, No. 10, Modèle No. 9.

Bulimina elegans Parker, Jones, and Brady, 1865, Ann. Mag. Nat. Hist., ser. 3, vol. 16, p. 20, pl. ii, fig. 64.

Bulimina elegans Brady, 1884, Challenger Report, vol. 9, p. 398, pl. l, figs. 1–4.

Bulimina elegans Jones, 1895, Mon. Foram. Crag, pt. 2 (Pal. Soc.), pp. 162, 163, woodcut, fig. 17.

Bulimina elegans Woodward, 1898, Jour. New York Microsc. Soc., pp. 1, 3.

Bulimina elegans Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 244, pl. xxix, fig. 3.

Test small, with rapidly expanding triserial chambers, which are globose, with deep depressions between each. Professor Brady considered this form as a central type of a somewhat numerous group of recent Buliminæ.

The geological range of the species is from Upper Cretaceous to Recent.

Mr. Chapman describes it from the upper Chalk, Egger from the older Pliocene, T. Rupert Jones from the Pliocene of England, and Woodward from the Miocene of New Jersey and Alabama. The species is common in the California Miocene material.

BULIMINA ELEGANTISSIMA d'Orbigny.

Pl. II, fig. 4.

Bulimina elegantissima d'Orbigny, 1839, Foram. Amérique Mérid., p. 51, pl. vii, figs. 13, 14.

Bulimina elegantissima Williamson, 1858, Recent Foram. Great Britain, p. 64, pl. v, figs. 134, 135.

Bulimina pulchra Terquem, 1882, Mém. Soc. Géol. France, sér. 3, vol. 2, mém. 3, p. 114, pl. xii, figs. 8–12.

Bulimina elegantissima Brady, 1884, Challenger Report, vol. 9, pp. 402, 403, pl. l, figs. 20–22.

Bulimina elegantissima Woodward, 1898, Jour. New York Microsc. Soc., p. 3.

Bulimina elegantissima Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 243, pl. xxix, fig. 2.

"The test of *Bulimina elegantissima*, as portrayed by d'Orbigny, is distinctly and regularly spiral. It consists of from two to three convolutions, the last of which occupies more than three-fourths of the visible shell. The chambers number from seven to ten in the final whorl; they are long in the direction of the axis of the test, narrow and obliquely set, and the sutures are only slightly excavated."[a]

The California forms which belong under this species are smaller than some of the other Buliminæ associated with it, and their chambers are not so definitely arranged in triserial oblique spire as in the more typical forms. The species is not uncommon, and Chapman states that it is frequent in the Miocene of Santa Clara County, Cal.

As a fossil it is first recorded from the Eocene of the Isle of Wight (Brady), in the Eocene of Paris (Terquem), and in the post-Tertiary clays of Norway. It is found at very shallow depths in existing oceans.

BULIMINA ELONGATA d'Orbigny.

Pl. II, fig. 5.

Bulimina elongata d'Orbigny, 1826, Annales Sciences Naturelles, vol. 7, p. 269, No. 9.

Bulimina elongata d'Orbigny, 1846, Foram. Foss. Vienne, p. 187, pl. xi, figs. 19, 20.

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Bulimina elongata Brady, 1884, Challenger Report, vol. 9, pp. 401, 402, pl. li, figs. 1 (and 2?).

Bulimina elongata Woodward, 1898, Jour. New York Microsc. Soc., p. 1.

Bulimina elongata Bagg, 1898, Bull. American Paleont., vol. 2, No. 10, p. 316.

Bulimina elongata Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 243, pl. xxix, fig. 1.

The test of *Bulimina elongata* is, as its name implies, much attenuated, though it tapers but slightly from end to end. The segments are

[a] Brady, Challenger Report, vol. 9, 1884, p. 402.

short, oval, and somewhat irregularly arranged with lobulated margins, not smooth as in *B. imbricata* Reuss, which it somewhat resembles. The primordial end is sharply, the anterior obtusely, rounded, with numerous chambers of irregular size separated by depressed septa. The ultimate chamber is provided on its lower surface with a comma-shaped aperture.

This is a very common form in the California Miocene. As a fossil its earliest appearance is in the lower Tertiary. Brady mentions the species at depths of 630 fathoms in the North Atlantic and of 1,425 fathoms in the South Atlantic.

BULIMINA OVATA d'Orbigny.

Pl. III, fig. 1.

Bulimina ovata d'Orbigny, 1846, Foram. Foss. Vienne, p. 185, pl. xi, figs. 13, 14.
Bulimina pedunculata Costa, 1856, Atti Accad. Pontaniana, vol. 7, p. 334, pl. xviii, fig. 13.
Bulimina ovata Parker and Jones, 1865, Philos. Trans., vol. 155, p. 374, pl. xvii, fig. 67a, 67b.
Bulimina ovata Brady, 1884, Challenger Report, vol. 9, p. 400, pl. l, fig. 13a, b.
Bulimina ovata Egger, 1895, Jahrsber. Naturhist. Ver. Passau, vol. 16, p. 15, pl. iii, fig. 11a, b.

The test is characterized by its oval outline. From the cylindrical center the shell tapers rapidly at each end and these are rounded, not pointed as in *Bulimina affinis*. This species is less frequent than *B. affinis*, which it closely resembles. Its geological distribution begins with the Eocene and it is common in shore sands of the British Isles. In the North Atlantic it occurs at various depths down to 1,400 fathoms. In the South Atlantic, Brady records its occurrence as deep as 2,200 fathoms and in the South Pacific at from 15 to 580 fathoms.

BULIMINA PUPOIDES d'Orbigny.

Pl. III, fig. 2.

Bulimina pupoides d'Orbigny, 1846, Foram. Foss. Vienne, p. 185, pl. xi, figs. 11, 12.
Bulimina pupoides Williamson, 1858, Recent Foram. Great Britain, p. 62, pl. v, figs. 124, 125.
Bulimina pupoides Terrigi, 1880, Atti Accad. Pontificia Nuovi Lincei, vol. 33, p. 193, pl. ii, figs. 30–34.
Bulimina pupoides Brady, 1884, Challenger Report, vol. 9, pp. 400, 401, pl. l, fig. 15a, b.
Bulimina pupoides Egger, 1895, Jahrsber. Naturhist. Ver. Passau, vol. 16, p. 14, pl. iv, figs. 6a, 6b, 7, 8.

Test composed of rapidly enlarging oval segments arranged spirally and with depressed septal lines between each. The initial chamber is not as sharp and the termination is less acute than in *Bulimina affinis*, which it closely resembles. It is not so regularly built as *Bulimina ovata* and the segments are more distinct and separate. The three forms are so nearly related that it is difficult to decide with certainty

into which division the specimens should be placed. It would have been wise to have made these forms varieties of one species, but they have been held as distinct so long and by so many authors that it seems best to keep them as species still. This form is rare as compared with other types in the California Miocene. The species has a length of 0.25 mm. Geologically the species has the same range as its relatives, but Woodward and Thomas report it in the Cretaceous of Minnesota. The shallow-water deposits of many oceans yield specimens of *Bulimina pupoides*, and it ranges from shoal depths down to 1,000 fathoms.

Genus BOLIVINA d'Orbigny (1839).

BOLIVINA ÆNARIENSIS (Costa).

Pl. III, fig. 3.

Brizalina ænariensis Costa, 1856, Atti Accad. Pontaniana, vol. 7, p. 297, pl. xv, fig. 1, A, B.

Bolivina ænariensis Brady, 1884, Challenger Report, vol. 9, p. 423, pl. liii, figs. 10, 11.

Bolivina ænariensis Jones, 1895, Mon. Foram. Crag (Pal. Soc.), pt. 2, pp. 169, 170, pl. vi, fig. 21.

Bolivina ænariensis Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 246, pl. xxix, fig. 8.

The genus *Bolivina* is one of the most common types found in the California Miocene and it is represented by many species. The form described by Costa under the term *Brizalina* has a fairly regular outline, elongated, tapering, and having the surface marked by lines which resemble delicate costæ, but which are said to be due to two tubular internal siphons. The striæ in the California specimens run about two-thirds up and are very delicate and not easily discernible. The presence of striations, the sharp peripheral margin, and the elongated flattened outline afford means of identifying this shallow-water species.

At the present time the best specimens, according to Prof. H. B. Brady, come from the North Atlantic, but the species is found northwest of Ireland, in the Faroe Channel, near the Philippine Islands, on the south coast of Japan, and at the mouth of the Rio de la Plata. Mr. Chapman's specimens were from a well in Santa Clara County, Cal. Costa's specimens were from the Tertiary beds of Casamicciola, Ischia.

The geological range is from the Miocene to Recent, but the form is more abundant in the middle and late Tertiary.

BOLIVINA DILATATA Reuss.

Pl. III, fig. 4.

Bolivina dilatata Reuss, 1849, Denkschr. K. Akad. Wiss. Wien, vol. 1, p. 381, pl. xlviii, fig. 15.

Bolivina dilatata Terrigi, 1880, Atti Accad. Pontificia Nuovi Lincei, vol. 33, p. 197, pl. ii, fig. 42.

Bolivina dilatata Brady, 1884, Challenger Report, vol. 9, p. 418, pl. lii, figs. 20, 21.
Bolivina dilatata Egger, 1895, Jahrsber. Naturhist. Ver. Passau, vol. 16, pp. 10, 11, pl. i, figs. 6a–c.
Bolivina dilatata Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 245, pl. xxix, fig. 6.

The test of *Bolivina dilatata* is broadly expanded at its final segment, and the long rather narrow intermediate chambers taper rapidly to the initial chamber. The lateral margins terminate acutely, and the form varies considerably in size, length, and amount of expansion, but the fossil specimens so abundant in the California Miocene are typical.

As a fossil *Bolivina dilatata* first appears in the Miocene, and is living to-day at various stations in the North Atlantic Ocean. It occurs in dredgings from a few to 1,180 fathoms.

Bolivina dilatata var. angusta Egger.

Pl. III, fig. 5.

Bolivina dilatata var. *angusta* Egger, 1895, Jahrsber. Naturhist. Ver. Passau, vol. 16, p. 11, pl. i, figs. 7, 12a, b.
Bolivina dilatata var. *angusta* Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 245, pl. xxix, fig. 7.

The variety of *Bolivina dilatata* figured by Egger under the name *angusta* differs from the type only in the unimportant features of a longer, more tapering test, an increased number of lateral chambers, and more acute ending of the distal chamber. Egger's forms were from the Pliocene of Monte Bartolomeo. The variety is a little less frequent than the type in the California Miocene.

Bolivina punctata d'Orbigny.

Pl. III, fig. 6.

Bolivina punctata d'Orbigny, 1839, Foram. Amérique Mérid., p. 63, pl. viii, figs. 10–12.
Bolivina antiqua d'Orbigny, 1846, Foram. Foss. Vienne, p. 240, pl. xiv, figs. 11–13.
Bolivina punctata Macdonald, 1857, Ann. Mag. Nat. Hist., ser. 2, vol. 20, p. 193, pl. vi, figs. 26, 27.
Bolivina punctata Brady, 1884, Challenger Report, vol. 9, p. 417, pl. lii, figs. 18, 19.
Bolivina punctata Woodward and Thomas, 1884 (1885), Thirteenth Ann. Rept. Geol. Nat. Hist. Survey Minnesota, p. 169, pl. iii, fig. 12.
Bolivina punctata Bagg, 1898, Bull. U. S. Geol. Survey No. 88, p. 33, pl. ii, fig. 3.

The test of *Bolivina punctata* is typically represented by an elongated textulariform arrangement of short chambers and the segments are more numerous than in most of the *Bolivina* forms. The term *Bolivina antiqua* has been used by d'Orbigny, Bronn, Costa, Egger, Terrigi, and perhaps others for this same species, but it seems best to the writer to regard *B. antiqua* as a synonym of the earlier name

given by d'Orbigny. The specimen d'Orbigny described as *B. antiqua* is undoubtedly only a modification of *B. punctata*, and there is no good ground for separating the two even under varieties.

This species is from the Tertiary to the Recent. It occurs to-day in all oceans and at all possible depths.

Bolivina punctata var. substriata Egger.

Pl. III, fig. 7.

Bolivina punctata var. *substriata* Egger, 1893, Abhandl. K. bayer. Akad. Wiss., p. 298, pl. viii, figs. 4–6.

Bolivina punctata var. *substriata* Egger, 1895, Jahrsber. Naturhist. Ver. Passau, vol. 16, p. 11, pl. i, fig. 14, a, b.

The form figured by Egger as a variety of *B. punctata* differs from the type by the presence of a number of striations which run from the primordial chamber for about one-half the distance of the entire shell. The forms from California are more slender than *B. punctata* and are less abundant. The geological range is similar to that of *B. punctata*.

Bolivina textilarioides Reuss.

Pl. IV, fig. 1.

Bolivina textilarioides Reuss, 1862, Sitzungsber. K. Akad. Wiss. Wien, vol. 46, p. 81, pl. x, fig. 1.

Bolivina textilarioides (*textularioides*) Berthelin, 1880, Mém. Soc. Géol. France, sér. 3, vol. 1, p. 28, pl. i (xxiv), fig. 5.

Bolivina textilarioides Terrigi, 1883, Atti Accad. Pontificia Nuovi Lincei. vol. 35, p. 191, pl. iii, fig. 32.

Bolivina textilarioides Brady, 1884, Challenger Report, vol. 9, p. 419, pl. lii, figs. 23–25.

Bolivina textilarioides Brady, Parker, and Jones, 1888, Trans. Zool. Soc., vol. 12, pt. 7, p. 221, pl. xliii, fig. 1.

Bolivina textilarioides (*textularioides*) Egger, 1895, Jahrsber. Naturhist. Ver. Passau, vol. 16, p. 12, pl. i, fig. 8.

Bolivina textilarioides is shorter and considerably broader than *Bolivina punctata* or *B. antiqua*, which it closely resembles. Is has chambers less high or arched and the margin is more nearly round. Chambers vary from six to eight on each side and the shell in general appearance resembles *Textularia*, but the test is calcareous with fine but very distinct pores. The original spelling of the species is *textilarioides*, not *textularioides* as is adopted by many authors. The original name should stand, although Reuss used the old spelling for the species, evidently after *Textularia*, the well-known genus which the species resembles. The fossil is rather rare in the California Miocene. Its geological range extends from the Cretaceous through the Tertiary, and at the present day it is found in many localities in comparatively shoal waters and occasionally at considerable depths.

Family LAGENIDÆ.

Subfamily LAGENINÆ.

Genus LAGENA Walker and Boys (1784).

LAGENA APICULATA Reuss.

Pl. IV, fig. 2.

Oolina apiculata Reuss, 1850, Haidinger's Naturw. Abhandl., vol. 4, p. 22, pl. i, fig. 1.
Lagena apiculata Reuss, 1862, Sitzungsber. K. Akad. Wiss. Wien, vol. 46, p. 319, pl. i, fig. 1.
Lagena apiculata Jones, Parker, and Brady, 1866, Foram. Crag, Pal. Soc., vol. 19, p. 44, pl. i, fig. 27.
Lagena apiculata Brady, 1884, Challenger Report, vol. 9, p. 453, pl. lvi, figs. 4, 15–18.
Lagena apiculata Sherborn and Chapman, 1886, Jour. Roy. Microsc. Soc., ser. 2, vol. 6, p. 744, pl. xiv, fig. 14.

This form is found more frequently in fossil beds than any other species of *Lagena*, occurring as far back as the Lias and extending to the present. It is present in all oceans and at every depth down to nearly 3,000 fathoms. The form is similar to *Lagena globosa*, but is separated from it by the spinous prolongation on the posterior portion of the shell. The short diameter of the only specimen of this species in the present collection measures 0.15 mm.

LAGENA GLOBOSA (Montagu).

Pl. IV, fig. 3.

Vermiculum globosum Montagu, 1803, Test. Brit., p. 523.
Entosolenia globosa Parker and Jones, 1857, Ann. Mag. Nat. Hist., ser. 2, vol. 19, p. 278, pl. xi, figs. 25–29.
Entosolenia globosa Williamson, 1858, Recent Foram. Great Britain, p. 8, pl. i, figs. 15, 16.
Lagena globosa Reuss, 1863, Sitzungsber. K. Akad. Wiss. Wien, vol. 46, p. 318, pl. i, figs. 1–3.
Lagena globosa Terquem, 1876, Anim. Plage Dunkerque (2), p. 67, pl. vii, figs. 3, 4.
Lagena globosa Brady, 1884, Challenger Report, vol. 9, pp. 452, 453, pl. lvi, figs. 1, 2, 3.
Lagena globosa Bagg, 1898, Bull. American Paleont., vol. 2, No. 10, pp. 317, 318.

Test subglobular, elliptical or pyriform, smooth, anterior margin somewhat projecting; cell walls thin, hyaline, aperture typically an entosolenian neck. It was discovered by the writer in the Pleistocene marl of Cornfield Harbor, Md., and the California Miocene has furnished one specimen. Its geological range is from the Jura to the present; it is possible that it existed in Carboniferous time. It is known in every ocean and at all depths.

LAGENA GRACILIS Williamson.

Pl. IV, fig. 4.

Lagena gracilis Williamson, 1848, Ann. Mag. Nat. Hist., ser. 2, vol. 1, p. 13, pl. i, figs. 3, 4.

Lagena gracilis Reuss, 1862, Sitzungsber. K. Akad. Wiss. Wien., vol. 46, p. 331, pl. iv, figs. 58–61; pl. v, fig. 62.

Lagena gracilis Brady, 1884, Challenger Report, vol. 9, p. 464, pl. lviii, figs. 2, 3, 7–10, 19, 22–24.

This finely costate or striated *Lagena* is much longer than *Lagena sulcata*, and is further distinguished by the presence of a small spine at the distal end. The neck is long, tubular, and in our specimen there are only a few striations along the shell surface. Brady considers the typical forms a modification of *Lagena clavata*. The only specimen in the present collection is 0.2 mm. in length.

It is of world-wide distribution at the present day, and is usually found in shallow waters, but it is known in many instances to occur as deep as 2,775 fathoms in the South Atlantic Ocean. Its geological range is from Cretaceous to Recent.

LAGENA MARGINATA (Walker and Boys).

Pl. IV, fig. 5.

Serpula marginata Walker and Boys, 1784, Test. Min., p. 2, pl. i, fig. 7.

Vermiculum marginatum Montagu, 1803, Test. Brit., p. 524.

Oolina compressa d'Orbigny, 1839, Foram. Amérique Mérid., p. 18, pl. v, figs. 1, 2.

Lagena sulcata var. *marginata* Parker and Jones, 1865, Philos. Trans., vol. 155, p. 355, pl. xiii, figs. 42–44; pl. xvi, fig. 12a, b.

Lagena marginata Brady, 1884, Challenger Report, vol. 9, pp. 476, 477, pl. lix, figs. 21–23.

The interesting species *Lagena marginata* was observed in the California Miocene, but unfortunately the single specimen was lost in transferring and no duplicate was discovered.

The form observed was similar to fig. 22, pl. lix, Challenger Report. The test of *Lagena marginata* is oval or rounded in outline, with more or less lateral compression, and with the periphery ending in a carina, or double ridge or groove, or in exceptional cases extended into a flange-like lamella, with a width of one-third the diameter of the shell. Aperture is an external fissurine opening, extending from an entosolenian neck. The species is widely distributed at the present time, being found from the most northern arctic waters southward to the Antarctic Circle, and at every depth down to 3,125 fathoms.

As a fossil it first appears in the Cretaceous, and is described from every subsequent formation.

LAGENA SULCATA (Walker and Jacob).

Pl. IV, fig. 6.

Serpula sulcata Walker and Jacob, 1798, Adam's Essays, Kanmacher's ed., p. 634, pl. xiv, fig. 5.
Ovulina sulcata Seguenza, 1862, Foram. Monotal. Messina, p. 41, pl. i, fig. 8.
Lagena sulcata Parker and Jones, 1865, Philos. Trans., vol. 155, p. 351, pl. xiii, figs. 24m, 28–32; pl. xvi, figs. 6, 7.
Lagena sulcata Brady, 1884, Challenger Report, vol. 9, pp. 462, 463, pl. lvii, figs. 23, 26, 33, 34; apiculate forms, pl. lviii, figs. 4, 17, 18.
Lagena sulcata Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 246, pl. xxix, fig. 9.

The species includes noncompressed forms which have their surface ornamented by longitudinal costæ. Only one specimen was found, the California Miocene, and it has about ten or twelve delicate superficial striations distinctly visible under low power. The form is elongated oval with a slightly extended aperture of the fissurine type.

Geologically the form is one of the oldest types of *Lagena* known, and has been discovered in upper Silurian shales at Woolhope by John Smith. It is known in every latitude at depths of from a few down to 2,750 fathoms, though the species is normally present in shallow waters.

Subfamily NODOSARINÆ.

Genus NODOSARIA Lamarck (1816).

NODOSARIA ADOLPHINA d'Orbigny.

Pl. V, fig. 1.

Dentalina adolphina d'Orbigny, 1846, Foram. Foss. Vienne, p. 51, pl. ii, figs. 18–20.
Dentalina adolphina Bornemann, 1855, Zeitschr. Deutsch. geol. Gesell., vol. 7, p. 324, pl. xiii, fig. 5.
Dentalina adolphina Sherborn and Chapman, 1886, Jour. Roy. Microsc. Soc., ser. 2, vol. 6, p. 750, pl. xv, figs. 11a, b, 12.
Nodosaria adolphina Bagg, 1898, Bull. U. S. Geol. Survey No. 88, p. 37 (spelled erroneously adolphinula).
Nodosaria adolphina Chapman, 1900, Proc. Acad. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 249, pl. xxix, fig. 16.

In large typical specimens of *N. adolphina* the segments are ornamented upon the posterior margin by spines, but in the California forms these appear to be wanting and the shells are apparently young and very minute. The peculiar shape of the constrictions and segmentation serves to furnish a basis for the placing of these California specimens under the above-named species. The species occurs from the Cretaceous to Recent, but is chiefly found in the Tertiary.

NODOSARIA COMMUNIS (d'Orbigny).

Pl. V, fig. 2.

Dentalina communis ?d'Orbigny, 1826, Annales Sciences Naturelles, vol. 7, p. 254, No. 35.

Dentalina communis d'Orbigny, 1840, Mém. Soc. Géol. France, vol. 4, p. 13, pl. i, fig. 4.

Nodosaria communis Reuss, 1845, Verstein. böhm. Kreid., pt. 1, p. 28, pl. xii, fig. 21.

Dentalina communis Reuss, 1860, Sitzungsber. K. Akad. Wiss. Wien, vol. 40, p. 186.

Dentalina legumen Reuss, 1860, Sitzungsber. K. Akad. Wiss. Wien, vol. 40, p. 186.

Nodosaria communis Brady, 1884, Challenger Report, vol. 9, pp. 504, 505, pl. lxii, figs. 19–22.

Nodosaria communis Egger, 1895, Jahrsber. Naturhist. Ver. Passau, vol. 16, p. 20, pl. ii, figs. 1, 2.

Only one specimen of *Nodosaria communis* was found in the material under investigation. This has but three segments, and is probably a young form. It is 0.4 mm. long. The segments are obliquely set, marked by depressed septa, not flush as in *N. roemeri*, and the shell is slightly arcuate as in typical specimens of greater length. The geological distribution of the species is, from the Permian to Recent, like *N. farcimen*. It is found to-day at every depth and in every latitude.

NODOSARIA CONSOBRINA d'Orbigny.

Pl. V, fig. 3.

Dentalina consobrina d'Orbigny, 1846, Foram. Foss. Vienne, p. 46, pl. ii, figs. 1–3.

Dentalina consobrina Neugeboren, 1856, Denkschr. K. Akad. Wiss. Wien, vol. 12, p. 86, pl. iii, fig. 15.

Nodosaria consobrina Brady, 1884, Challenger Report, vol. 9, p. 501, pl. lxii, figs. 23, 24.

The typical forms of *Nodosaria consobrina* are marked by smooth, attenuate, elongated shells with frequently irregular chambers, which are not as compactly built as in the variety of this species, and with a more enlarged ultimate and initial chambers, the latter often provided with a spine, as in d'Orbigny's original figure. There are only a few specimens of this species in the California Miocene. They are more regular than typical forms, and there is no terminal spine upon the primordial segment. The shells are similar to *N. consobrina* var. *emaciata*, but the smaller number of chambers and their larger size may be used to distinguish the two forms.

The geological and geographical range is similar to the variety *emaciata*, described on page 30. The broken segments of the specimens with eight chambers are 0.8 mm. in length.

NODOSARIA CONSOBRINA var. EMACIATA Reuss.

Pl. V, fig. 4.

Dentalina emaciata Reuss, 1851, Zeitschr. Deutsch. geol. Gesell., vol. 3, p. 63, pl. iii, fig. 9.

Nodosaria (D.) consobrina var. *emaciata* Reuss, 1865, Denkschr. K. Akad. Wiss. Wien, vol. 25, p. 132, pl. ii, figs. 12, 13.

Nodosaria consobrina var. *emaciata* Brady, 1884, Challenger Report, vol. 9, p. 502, pl. lxii, figs. 25, 26.

Nodosaria consobrina var. *emaciata* Bagg, 1898, Bull. U. S. Geol. Survey No. 88, p. 38.

Nodosaria consobrina var. *emaciata* Bagg, 1898, Bull. American Paleont., vol. 2, No. 10, p. 319.

Test very long, smooth, tapering gracefully, with numerous compact, closely set segments, only slightly expanding, separated by septa but little depressed, set straight across the chambers. Similar to *Nodosaria consobrina*, but more slender and elongated and with more chambers in proportion to its length. Initial segment neatly rounded, but little marked off from the second and third chambers, which can not be easily distinguished. Only a few specimens are present in the California Miocene. The species is found in all rocks from Cretaceous to Recent.

Brady, in the Challenger Report, states that the species is living in the North Atlantic at depths of from 290 to 725 fathoms; in the South Atlantic at 350 fathoms; off the Cape of Good Hope at 150 fathoms, and in the South Pacific from 129 to 1,375 fathoms. No specimens were obtained by the Challenger from the North Pacific. Length of broken specimen of ten chambers is 1.1 mm.

NODOSARIA FARCIMEN (Soldani).

Pl. V, fig. 5.

Orthoceras farcimen Soldani, 1791, Testaceographia, vol. 1, pt. 2, p. 98, pl. cv, fig. 0.

Dentalina farcimen Reuss, 1861 (1863), Bull. Acad. Roy. Belgique, sér. 2, vol. 15, p. 146, pl. i, fig. 18.

Nodosaria farcimen Brady, 1884, Challenger Report, vol. 9, pp. 498, 499, pl. lxii, figs. 17, 18, and woodcuts, p. 499.

Nodosaria farcimen Bagg, 1898, Bull. U. S. Geol. Survey No. 88, pp. 38, 39.

Nodosaria farcimen Bagg, 1898, Bull. American Paleont., vol. 2, No. 10, pp. 25, 26, pl. i, fig. 2.

Nodosaria farcimen Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 248, pl. xxix, fig. 13.

The test of *Nodosaria farcimen* consists of a small number of smooth segments (generally less than ten) separated by straight instead of oblique septa, as in *N. communis*, which the species resembles. The chambers are longer than in *N. soluta*, and in the typical forms constricted rather deeply, each succeeding chamber enlarging rapidly. The shell is curved and the nipple-shaped aperture is located on the inner margin of the curve in a prolongation of the ultimate segment.

The length is extremely variable, being 2.82 mm. in the Cretaceous specimens and only 1.10 mm. in the Maryland Eocene. The California forms are smaller yet, and are so fragile that entire specimens are extremely difficult to obtain. The best form in the present collection has eight segments. The geological age of the species goes back to the Permian, and in existing seas it is known at almost every depth and in every ocean.

NODOSARIA FILIFORMIS (d'Orbigny).

Pl. V, fig. 6.

Nodosaria filiformis d'Orbigny, 1826, Annales Sciences Naturelles, vol. 7, No. 14, p. 253.

Nodosaria filiformis Brady, 1884, Challenger Report, vol. 9, p. 500, pl. lxiii, figs. 3–5.

The type represented by *Nodosaria filiformis* has been described under a variety of names which are given in the list of references in the Challenger Report. This synonymy is probably incomplete.

The shell is very long, slender, delicately built, slightly curved, and with many short, oval, smooth segments which taper gracefully to the primordial end. The septa are straight, depressed, not obliquely set as in *N. communis* and the ultimate chamber is prolonged into a nipple-shaped aperture.

This species is not uncommon in the California Miocene, but only fragments can be obtained. It is found in the Lias and every succeeding formation. It occurs in dredgings from a depth of a few feet to about 500 fathoms, but is not widely distributed.

NODOSARIA OBLIQUA (Linné).

Pl. V, fig. 7

Nautilus obliquus Linné, 1767, Syst. Nat., 12th ed., pp. 281, 1163; 1788, ibid., 13th (Gmelin's) ed., p. 3372, No. 14.

Orthocera obliqua Lamarck, 1822, Anim. sans Vert., vol. 7, No. 4, p. 594.

Dentalina obliqua Jones, Parker, and Brady, 1866, Foram. Crag, Pal. Soc., vol. 19, p. 54, pl. i, fig. 9.

Nodosaria obliqua Brady, 1884, Challenger Report, vol. 9, pp. 513, 514, pl. lxiv, figs. 20–22.

Nodosaria obliqua Bagg, 1898, Bull. U. S. Geol. Survey No. 88, p. 41.

Nodosaria obliqua Bagg, 1898, Bull. American Paleont., vol. 2, No. 10, p. 320.

Nodosaria obliqua Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 249, pl. xxix, fig. 17.

This species is exceedingly variable in size, length, and arcuate character, but the obliquely set striations, which run in more or less conflicting ends, together with the distinct ventricose segments with depressed septa, serve as sufficient aids in the determination of even fragments of this interesting species. If, as Brady and other authors have done, we include all forms with very numerous oblique stria-

tions, such as *Dentalina confluens*, *Nodosaria sulcata* Nilsson, *Dentalina steenstrupi* Reuss, etc., the synonymy becomes enormous. The species first appears in the lower Lias and is present in increasing numbers in all subsequent formations. In existing oceans it is found in every sea and at all possible depths down to 2,000 fathoms.

The California specimens of *Nodosariæ* are nearly always broken and compared with the forms found in the New Jersey Cretaceous are exceedingly small. *Nodosaria obliqua* is one of the rarest species found by the writer in the material submitted from California. This species was also found in material from the calcareous Tejon beds near New Idria, in De los Reyes Canyon, given to the author by Mr. T. W. Stanton, of the United States Geological Survey.

NODOSARIA PAUPERATA (d'Orbigny).

Pl. V, fig. 8.

Dentalina pauperata d'Orbigny, 1846, Foram. Foss. Vienne, p. 46, pl. i, figs. 57, 58.
Dentalina pauperata Bornemann, 1855, Zeitschr. Deutsch. geol. Gesell., vol. 7, p. 324, pl. xiii, fig. 7.
Dentalina pauperata Jones and Parker, 1860, Quart. Journ. Geol. Soc. London, vol. 16, p. 453, pl. xix, fig. 22.
Nodosaria pauperata Brady, Challenger Report, vol. 9, p. 500, woodcuts a, b, c.
Dentalina pauperata Sherborn and Chapman, 1886, Jour. Roy. Microsc. Soc., ser. 2, vol. 6, p. 750, pl. xv, fig. 9.
Nodosaria pauperata Jones, 1896, Mon. Foram. Crag, pt. 3, 1895, pp. 224–226, pl. i, figs. 13–18, 20.
Nodosaria pauperata Bagg, 1898, Bull. U. S. Geol. Survey No. 88, p. 42.
Nodosaria pauperata Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 247, pl. xxix, fig. 12.

Test smooth, somewhat arcuate, tapering very slightly and with chambers of nearly uniform size, with little or no constrictions in lower portion. The sutures become more pronounced at the ultimate end. In the California specimens the initial segment is enlarged and the posterior rounded, not aciculate as in some of the specimens placed under this species. The geological range begins with the Lias and extends to the present. Found at all depths and in all oceans.

NODOSARIA RADICULA (Linné).

Pl. V, fig. 9.

Nautilus radicula Linné, 1767, Syst. Nat., 12th ed., pp. 285, 1164; 1788; Gmelin's ed., vol. 1, pt. 6, p. 3373, No. 18.
Nautilus radicula Montagu, 1803, Test. Brit., p. 197, pl. vi, fig. 4.
Nodosaria radicula d'Orbigny, 1826, Annales Sciences Naturelles, vol. 7, p. 252, No. 3, Modèle No. 1.
Nodosaria radicula Brady, 1884, Challenger Report, vol. 9, p. 495, pl. lxi, figs. 28–31.
Nodosaria radicula Agassiz, 1888, Three Cruises "Blake," vol. 2, p. 166, fig. 504.
Nodosaria radicula Bagg, 1898, Bull. U. S. Geol. Survey No. 88, p. 42.
Nodosaria radicula Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 247, pl. xxix, fig. 11.

The test of *Nodosaria radicula* is characterized by a straight, closely built shell of but few chambers, having a smooth surface and straight septa. The chambers are globular, constricted, and relatively large in proportion to the length of the shell as compared with some of the more tapering *Nodosariæ*. The California forms have the primordial chamber slightly enlarged, and in some specimens there are six or seven chambers preserved, although every one of them examined is broken. The constrictions become more pronounced toward the ultimate segment. The specimens obtained by the writer from the New Jersey Cretaceous measured 2 mm. in length. The California forms are much smaller. Brady, in the Challenger Report, speaks of the distribution of the species as follows: "*Nodosaria radicula* has a wide area of distribution. It is found in the Arctic seas, and on the shores of Norway and of the British islands; in the North Atlantic, from shallow water to a depth of 1,360 fathoms; in the South Atlantic as deep as 2,350 fathoms, and in the South Pacific from 37 to 1,100 fathoms, and it also occurs in the Adriatic. It has not been observed in the North Pacific."

Its fossil range dates from the Permian, and it is known throughout the Cretaceous and Tertiary formations in many regions.

NODOSARIA ROEMERI (Neugeboren).

Pl. V, fig. 10.

Dentalina roemeri Neugeboren, 1856, Denksch. K. Akad. Wiss. Wien, vol. 12, p. 82, pl. ii, figs. 13–17.
Nodosaria roemeri Reuss, 1870, Sitzungsber. K. Akad. Wiss. Wien, vol. 62, p. 475.
Nodosaria roemeri Schlicht, 1870, Foram. Pietzpuhl., pl. x, figs. 21, 22, 24.
Nodosaria roemeri Brady, 1884, Challenger Report, vol. 9, pp. 505, 506, pl. lxiii, fig. 1.

The shell of *Nodosaria roemeri* resembles *Nodosaria communis* in its obliquely set septal partitions, but in the latter the sutures are depressed, while in *N. roemeri* they remain flush with the surface of the test. The form is stoutly built in proportion to its length, and the later chambers are much longer and larger than the earlier segments. The form is approximately straight, but in some specimens figured there is a limited amount of curvature, as in the earlier *Dentalina* types. The distal end is neatly rounded, in which respect it differs from *N. mucronata*. It is very rare in the California Miocene, and only one specimen was found, with four chambers preserved, the length of which is 2.3 mm.

The species is not common in existing oceans, but Prof. H. B. Brady reports its occurrence in the North Atlantic, where it chiefly occurs at depths of less than 400 fathoms. Its geological range is from Cretaceous to Recent.

NODOSARIA SOLUTA (Reuss).

Pl. V, fig. 11.

Dentalina soluta Reuss, 1851, Zeitschr. Deutsch. geol. Gesell., vol. 3, p. 60, pl. iii, fig. 4, a, b.

Nodosaria soluta Reuss, 1865, Denkschr. K. Akad. Wiss. Wien, vol. 25, p. 131, pl. ii, figs. 4–8.

Nodosaria soluta Brady, 1884, Challenger Report, vol. 9, p. 503, pl. lxii, figs. 13–16, var. pl. lxiv, fig. 28.

Nodosaria soluta 1886, Sherborn and Chapman, Jour. Roy. Microsc. Soc., ser. 2, vol. 6, p. 746, pl. xiv, figs. 25, 26.

Nodosaria soluta Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 248, pl. xxix, fig. 14.

The above species is represented only by fragments, the smaller of which pass into *N. adolphina* with their deep constricted segments. The large almost globular segments with smooth surface of only a small number of chambers serve to distinguish the species. The forms in the collection studied are not mucronate. The shell is either bent or straight, and varies greatly in size and length. Common to-day in the North Atlantic at depths from 300 to as low as 1,360 fathoms (Brady); South Atlantic, 350 to 675 fathoms; South Pacific, only from 125 to 410 fathoms (one instance 1,350) (Brady). The geological range is from Cretaceous to Recent. It is one of the most common *Nodosariæ* in the California material.

Genus CRISTELLARIA Lamarck (1816).

CRISTELLARIA ARTICULATA (Reuss).

Pl. VI, fig. 1.

Robulina articulata Reuss, 1863, Sitzungsber. K. Akad. Wiss. Wien, vol. 48, p. 53, pl. v, fig. 62.

Cristellaria articulata Reuss, 1870, Sitzungsber. K. Akad. Wiss. Wien, vol. 62, p. 483.

Cristellaria articulata Brady, 1884, Challenger Report, vol. 9, p. 547, pl. lxix, figs. 10–12.

Cristellaria articulata Bagg, 1898, Bull. U. S. Geol. Survey No. 88, p. 54.

The test of *Cristellaria articulata* is to be regarded as a thickened form of *Cristellaria rotulata*, and it must not be confounded with *Cristellaria articulata* Seguenza. The shell is nearly circular, smooth, thickened, flattened at the sides, and with an obtusely angular periphery. There are six or seven broadly triangular chambers, separated by depressed septa, which are somewhat curved backward and sickle-shaped. The aperture is an oval fissured opening close to the outer margin of the ultimate segment. The diameter of the specimens which the author found in the New Jersey Cretaceous measured 1.3 mm.

The writer has but one specimen, nearly perfect, from California, a trifle smaller than the above. The geological distribution is from the

Cretaceous to Recent. The species in existing oceans is mentioned by Brady as occurring at several stations at depths of less than 400 fathoms.

CRISTELLARIA CASSIS (Fichtel and Moll).

Pl. VI, fig. 2.

Nautilus cassis Fichtel and Moll, 1798, Test. Microsc., p. 95, pl. xvii, figs. a, 1.
Cristellaria cassis Lamarck, 1816, Tabl. Encycl. et Méthod., pl. cccclxvii, figs. 3 a–d.
Cristellaria cassis Brady, 1884, Challenger Report, vol. 9, pp. 552, 553, pl. lxviii, fig. 10.
Cristellaria cassis Bagg, 1898, Bull. U. S. Geol. Survey No. 88, p. 54.
Cristellaria cassis Silvestri, 1899, Mem. Accad. Lincei, vol. 15, pp. 206–212, pl. vii, figs. 13–17.
Cristellaria cassis Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, p. 250, pl. xxix, fig. 18.

There are several types of *Cristellaria cassis* given in descriptions of earlier authors. The test is complanate or nearly so in all, but frequently the exogenous tubercles or surface beading is entirely absent, and the presence of a well-defined keel, with complanate segmenta, serves to mark the species. The number of chambers in the final volution is fifteen in the New Jersey forms, but there are only six in the single California form. The sutures are depressed, arcuate, surface smooth, not beaded as in typical specimens. Mr. Chapman figures a variety from California with a serrated keel, but the margin is smooth, sharp, transparent, and of small width in the specimen we have identified. Breadth of shell is 0.25 mm. The geological range is from the Cretaceous to Recent. The bathymetric range at present is in shallow coral sands, and in the Adriatic, Mediterranean, etc., of shoal depths. The list of synonyms for the species is large, and there are many records of the species in the Tertiary deposits.

CRISTELLARIA CREPIDULA (Fichtel and Moll).

Pl. VI, fig. 3.

Nautilus crepidula Fichtel and Moll, 1803, Test. Microsc., p. 107, pl. xix, figs. g–i.
Cristellaria crepidula d'Orbigny, 1839, Foram. Cuba, p. 64, pl. viii, figs 17, 18.
Cristellaria crepidula Parker and Jones, 1865, Philos. Trans., vol. 155, p. 344, pl. xiii, figs. 15, 16, pl. xvi, fig. 4.
Cristellaria crepidula Brady, 1884, Challenger Report, vol. 9, pp. 542, 543, pl. lxvii, figs. 17, 19, 20; pl. lxviii, figs. 1, 2.
Cristellaria crepidula Bagg, 1898, Bull. U. S. Geol. Survey No. 88, p. 55.

The above list contains only a few of the many references for this interesting *Cristellaria*. The only specimen we have is broken, but exhibits the typical compressed elongate-oval outline, with oblique segments separated by depressed septa. The margin is sharp but not keeled, and the surface is smooth and white and glistening. The short diameter of this form is 0.25 mm.

The geographical range is very wide and it belongs to the shoal-water fauna, and only in one instance in the *Challenger* dredgings was the species detected in deep water (2,350 fathoms). Geologically it is known from the Lias and is present in greater abundance in succeeding formations.

CRISTELLARIA CREPIDULA (F. & M.) var. GLADIUS Philippi.

Pl. VI, fig. 4.

Marginulina gladius Philippi, 1843, Tertiär. nordwest. Deutsch., p. 40, pl. i, fig. 37.
Cristellaria crepidula var. *gladius* Burrows and Holland, 1897, Proc. Geologists' Assoc., vol. 15, pts. 1, 2, pp. 39, 40, pl. i, figs. 6, 9, 16.

Of all possible modifications, with an indefinite number of synonyms, variously described under both *Marginulina* and *Cristellaria*, this variety marks but one of perhaps the most variable of specific forms known among the Foraminifera. It is impossible, when the material from one locality shows such gradations as Burrows and Holland give in their paper on the Foraminifera of the Thanet Beds of Pegwell Bay, to consider more than mere varieties the large list of fossil-figured forms included under such names as *Cristellaria intermedia*, *C. simplex*, *C. cymboides*, *C. varians*, *C. protracta*, *C. harpa*, etc., of Reuss, d'Orbigny, d'Orbigny, Bornemann, Bornemann, and Reuss, respectively.

In De los Reyes Canyon and in the Tejon formation, near New Idria, Cal., there is one large (diameter long axis 1.1 mm.) ensiform *Cristellaria* belonging to the *crepidula* type and consisting of twelve chambers. The shell is compressed into an oval, slightly involute on the posterior end, and with extended evolute chambers on the anterior portion. There is a suggestion of angularity at the outer periphery without keel and the shell is arcuate. The form studied is most similar to the form figured by Burrows and Holland on pl. 1, fig. 6, in the above reference. The species must be considered a shallow-water form, and only in one instance were specimens dredged by the *Challenger* at a depth of over 2,000 fathoms (2,350).

The geological distribution of this species in some of its varieties is very extensive and is known in deposits as early as the Lias. It is also reported in the English chalk, the London clay, and in the later Tertiaries.

CRISTELLARIA (ROBULINA) GERLANDI Andreae.

Pl. VI, fig. 5.

Cristellaria (*Robulina*) *gerlandi* Andreae, 1884, Abhandl. Geol. Specialkarte Elsass-Lothringen, vol. 2, pt. 3, p. 208, pl. ix, fig. 25.

The form figured by Andreae under the name *Robulina gerlandi* is characterized by an exceedingly complanate suboval test with periph-

ery definitely keeled as in *C. cultrata*. The septal markings are wide and slightly depressed, and the septa are curved backward in the California specimen somewhat more than in the figure shown by Andreae. There are fourteen chambers in the California specimen, fifteen in Andreae's type. This complanate *Cristellaria* resembles *Cristellaria alberti* of Andreae, but the chambers are more numerous and the inner volution is distinct. Mr. Chapman in his report on the California fossils figures a new species of *Cristellaria* under the name *C. miocenica*, which is also closely related to the form under consideration, but his specimens did not exhibit the carinate feature seen in *C. gerlandi*. Andreae's form came from the Septaria clay of Unter-Elsass. There appears to be no other description of his peculiar species. The important feature of Andreae's type is the unsymmetrical development of the initial chamber which is slightly raised upon one side. This is less clearly seen in the California form, but the distinction is apparent upon close examination.

CRISTELLARIA GIBBA d'Orbigny.

Pl. V, fig. 6.

Cristellaria gibba d'Orbigny, 1839, Foram. Cuba, p. 63, pl. vii, figs. 20, 21.
Cristellaria gibba Brady, 1884, Challenger Report, vol. 9, pp. 546, 547, pl. lxix, figs. 8, 9.
Cristellaria gibba Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, pl. xxx, fig. 3.

Test oblong, biconvex, smooth; subcarinate, narrow; chambers few, seven or eight, slightly arcuate, separated by distinct septa; aperture marginate. The specimens found by the author in the New Jersey Cretaceous measured 1.3 mm. in length; 0.87 mm. in breadth.[a] This species resembles *C. acutauricularis*, but the septal face is more narrow. The above is exceedingly rare in the material under examination, and the writer has observed only one specimen. There are only five chambers in the elongated oblong-oval shell. The geological range is from the Cretaceous, possibly earlier, to the present time. The species does not seem to be abundant in existing oceans, and occurs sporadically at depths of less than 500 fathoms.

CRISTELLARIA ROTULATA (Lamarck).

Pl. V, fig. 7.

Lenticulites rotulata Lamarck, 1804, Ann. du Mus., vol. 5, p. 188, No. 3.
Cristellaria rotulata Brady, 1884, Challenger Report, vol. 9, p. 547, pl. lxix, fig. 13.
Cristellaria rotulata Dervieux, 1892, Boll. Soc. Geol. Italiana, vol. 10, p. 626.
Cristellaria rotulata Bagg, 1898, Bull. U. S. Geol. Survey No. 88, pp. 57, 58.

Test involute, biconvex, smooth; peripheral margin sharp, noncarinate; chambers numerous, but only eight or nine in final volution; septa moderately curved, visible externally as fine lines; aperture elliptical, radiate. The size of the shell is extremely variable. In

[a] Bull. U. S. Geol. Survey No. 88, p. 56.

the lime sand of New Jersey the author found specimens which measured over 2 mm. in diameter. The species is exceedingly rare in the California Miocene, and the genus is poorly represented in other types of *Cristellaria*. The geological range is from the Triassic to Recent. In nearly all existing oceans *Cristellaria rotulata* is abundant, and occurs at every depth from shore sands down to below 2,000 fathoms. The synonymy is altogether too cumbersome to be given here in full.

Subfamily POLYMORPHINÆ.

Genus UVIGERINA d'Orbigny (1826).

UVIGERINA CANARIENSIS d'Orbigny.

Pl. VI, fig. 1.

Uvigerina canariensis d'Orbigny, 1839, Foram. Canaries, p. 138, pl. i, figs. 25–27.
Uvigerina canariensis Brady, 1884, Challenger Report, vol. 9, pp. 573, 574, pl. lxxiv, figs. 1–3.
Uvigerina canariensis Woodward and Thomas, 1884 (1885), Thirteenth Ann. Rept. Geol. Nat. Hist. Survey Minnesota, p. 171, pl. iv, fig. 37.
Uvigerina canariensis Bagg, 1898, Bull. American Paleont., vol. 2, No. 10, pp. (31, 32), 325, 326.

The test of *Uvigerina canariensis* may well serve as a type of the rather uncommon, smooth-shelled forms of *Uvigerinæ*, nearly all being more or less ornamented with some form of surface striations. The form is irregularly triserial, elongate, built of projecting globose segments with well-defined septal constrictions between. It is quite likely that the form described as *Uvigerina urnula* by d'Orbigny in his Memoir on the Miocene Foraminifera of Vienna belongs under this species and the writer has so included it in a former publication.

The species is rather common in the California Miocene, but not nearly so frequent as its congenitor *Uvigerina tenuistriata*. It appears in the middle Tertiaries of many localities, and is rather widely distributed at the present time in existing oceans. Professor Brady mentions its occurrence in shore sands of Teneriffe, at a depth of 435 fathoms off Bermuda, of 150 fathoms near Cape of Good Hope, of 1,900 fathoms in the South Atlantic, and of 40 and 1,375 fathoms in the South Pacific. It has been found by several scientists on the coasts of the British Isles. The writer obtained this form from a well boring at Crisfield, Md. (Miocene), and also at Norfolk, Va.

UVIGERINA PYGMÆA d'Orbigny.

Pl. VII, fig. 2.

Uvigerina pygmæa d'Orbigny, 1826, Annales Sciences Naturelles, vol. 7, p. 269, pl. xii, figs. 8, 9, Modèles No. 67.
Uvigerina pygmæa d'Orbigny, 1846, Foram. Foss. Vienne, p. 190, pl. xi, figs. 25, 26.
Uvigerina pygmæa Brady, 1884, Challenger Report, vol. 9, p. 575, pl. lxxiv, typical figs. 11, 12 elongate forms figs. 13, 14.

The species was described and figured by the author[a] from the well-boring material of the Miocene from Crisfield, Md., and Norfolk, Va. The test is more or less broadly ovate and stoutly built with thick shell walls. The chambers are numerous, large, and globose, and are separated by depressed septa. The species is easy to recognize, for in addition to the above features the surface is marked by a number of longitudinal costæ, which are more abundant and more definite than in its congenitor *Uvigerina tenuistriata* Reuss. Both forms are frequently found in the same deposits. Its range is from the middle Tertiary to Recent, and the shell is universally distributed over nearly all waters at the present day. Its bathymetric range is from 200 to more than 2,500 fathoms. The fossil forms in California appear to belong mostly to *Uvigerina tenuistriata*, and only a few forms of the species under discussion were obtained.

UVIGERINA TENUISTRIATA Reuss.

Pl. VII, fig. 3.

Uvigerina tenuistriata Reuss, 1870, Sitsungsber. K. Akad. Wiss. Wien, vol. 62, p. 485.
Urigerina tenuistriata Schlicht, 1870, Foram. Pietzpuhl., pl. xxii, figs. 34–37.
Urigerina tenuistriata Brady, 1884, Challenger Report, vol. 9, p. 574, pl. lxxiv, figs. 4–7.
Urigerina tenuistriata Bagg, 1898, Bull. American Paleont., vol. 2, No. 10, pp. (32, 33).326, 327.
Urigerina tenuistriata Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 10, p. 252, pl. xxx, fig. 5.

The test of the above species is much more finely costate than *Uvigerina pygmæa* and it is more slender. It tapers to a neat well-rounded primordial segment, and enlarges by irregular sized chambers to the ultimate chamber. The septa are not as depressed as in *U. pygmæa* and the segments are less globose. The species terminates its ultimate chamber in the flaring tubular neck. Not uncommon in the California Miocene; rarer than *U. pygmæa* in the Maryland and Virginia Miocene. The shell is known from a number of localities in shallow waters. Its geological range is from Miocene to Recent.

Genus SAGRINA (d'Orbigny 1839) Parker and Jones.

The name *Sagrina* as given by d'Orbigny was applied to a biserial or Textulariform shell related to *Uvigerina* and provided with longitudinal striations. In his report of the Foraminifera of Cuba, d'Orbigny again applies the term to a rough dimorphous Textularian which differs from *Gaudryina* simply in the terminal aperture. The name appears therefore to have been used in different descriptions, but it has been revived and restricted by Parker and Jones to apply to a

[a] Tertiary and Pleistocene Foraminifera of the middle Atlantic slope: Bull. American Paleont., vol. 2, No. 10, p. 326, pl. xxii (2), fig. 8.

group of dimorphous *Uvigerinæ* whose biserial initial segments become Nodosarian in their ultimate growth. There seems to be but one step farther from a form which has but one or two biserial chambers to one in which the entire shell becomes a true Nodosarian in its type of development. The remarkable peculiarity of the aperture, however, is something altogether different from the typical *Nodosariæ*, and the arrangement of the chambers serves at once to separate the two genera as at present understood. While, therefore, at first the biserial growth, followed in its later stages by moniliform segmentation, must be regarded as representative of the type of the genus, we are forced to admit under the same a number of genera whose growth is altogether Nodosarian. The walls of the shell are invariably hyaline and perforate, and the surface decoration is extremely varied and beautiful. The genus first makes its appearance in the middle Tertiary, being known in Miocene, Pliocene, and Recent deposits.

In shallow waters of tropical oceans it exists to-day, and according to Brady it is generally limited to depths less than 200 fathoms. It is not a common form, though fairly widely distributed at the present time.

Synonymous terms for this genus are given by Prof. H. B. Brady in the Challenger Report, vol. 9, page 580. These are *Sagrina* (d'Orbigny, 1839); Parker and Jones (1865); Carpenter, Brady, Bütschli; *Sagraina*, Reuss (1861), Zittel, Schwager, Marsson; *Dimorphina*, Schwager (1866), Hantken; *Siphogenerina*, Schlumberger (1883).

SAGRINA BRANNERI n. sp.

Pl. VII, fig. 4.

In the material from California occur a large number of Nodosarian types with expanded elongated apertures of the *Sagrina* type. The surface is decorated with a large number of longitudinal costæ, as many as twenty occurring on some specimens. There are three distinct types of these, possibly more. These types are closely allied with the forms described and figured by Professor Brady in the Challenger Report under the name *Sagrina raphanus* Parker and Jones. They all differ from these figured types in the larger number of striations, and in the method of septal formation. In the California specimen the septa are arched between chambers and the arches extend from one surface costal ridge to another, and furthermore the striations are continuous, not broken, and extend to the very aperture, though the last chamber has them as fine lines running to the phialine aperture. The form selected to represent the species *Sagrina branneri* is acuminate and has about ten successive chambers closely set and with the surface marked by about sixteen longitudinal striations. Aperture raised, tubular, with flaring opening. Shell walls white, perforate. The form is large, nearly one-sixteenth inch in length.

SAGRINA CALIFORNIENSIS n. sp.

Pl. VII, fig. 5.

The *Sagrina* selected as a type for this species consists of a number of obtusely rounded shells with a more or less barrel-shaped outline due to an enlargement of the median chambers and a very slight tapering at both ends. There are ten chambers in most forms, which are compactly joined along a zigzag suture line, and the surface is deeply inset between large longitudinal costæ which run the entire length in unbroken ridges upon the shell. The aperture is tubular, flaring, short. This is the most common of the three types observed.

SAGRINA ELONGATA n. sp.

Pl. VII, fig. 6.

The form of *Sagrina elongata* is but little longer than its associate species, but it is considerably smaller and more slender, so that the test appears to possess considerable length. There is no swelling in the median portion and the margins are neatly rounded. Segments are ornamented similarly with the other types, though less prominently so. Common in the California Miocene.

Family GLOBIGERINIDÆ.

Genus GLOBIGERINA d'Orbigny (1826).

GLOBIGERINA BULLOIDES d'Orbigny.

Pl. VII, fig. 7.

Globigerina bulloides d'Orbigny, 1826, Annales Sciences Naturelles, vol. 7, p. 277, No. 1, Modèle No. 17 (young) and No. 76.

Globigerina hirsuta d'Orbigny, 1839, Foram. Canaries, p. 132, pl. ii, figs. 4–6.

Globigerina bulloides Brady, 1884, Challenger Report, vol. 9, pp. 593, 594, 595, pls. lxxvii, lxxix, figs. 3–7.

Globigerina bulloides Bagg, 1898, Bull. U. S. Geol. Survey No. 88, p. 63.

Globigerina bulloides Bagg, 1898, Bull. American Paleont., vol. 2, No. 10, p. 33.

Globigerina bulloides is one of the most widely distributed Foraminifera, occurring at the present time in every latitude and at all possible depths and being also found in numberless fossil localities in Cretaceous and later rocks. It is characterized by a spiral, subtrochoid test with globular chambers with deeply sunken umbilicus around which on the reverse side the spiral segments are wound and the number of chambers is varied in size, shape, and arrangement. In recent specimens about seven globose segments compose the final convolution. The forms found in the California Miocene are typical, for the species are frequent.

GLOBIGERINA BILOBATA d'Orbigny.

Pl. VII, fig. 8.

Globigerina bilobata d'Orbigny, 1846, Foram. Foss. Vienne, pp. 164, 165, pl. ix, figs. 11–14.

Globigerina bilobata Costa, 1856, Atti Accad. Pontaniana (2), vol. 7, p. 241, pl. xxi, fig. 6A, B.

Globigerina bilobata Brady, 1884, Challenger Report, vol. 9, p. 608, pl. lxxxi, figs. 20, 21; pl. lxxxii, figs. 2 and (3 ?) (here described under *Orbulina universa*).

Orbulina bilobata Egger, 1895, Jahrsber. Naturhist. Ver. Passau, vol. 16, p. 39, pl. iv, fig. 20, a, b.

This bilobate form resembles *Orbulina universa*, from which it is distinguished by being formed of two chambers which are not wholly distinct, but are united along a straight septal division and perhaps without aperture, although some figures show this feature. The perforations of the test are similar to those of *Orbulina universa*. One chamber is invariably somewhat larger than the other, although in some specimens this character is not pronounced. The species is not common and but few specimens have been detected in the material investigated. The longer diameter is 0.85 mm. and the diameter of the larger segment 0.6 mm. Fornasini has described this species in the Tertiary of Messina in 1893 and it is known in the Miocene of Monte Bartolomeo (Egger), the Miocene of the Vienna basin (d'Orbigny), and it is possibly coextensive with *Orbulina universa*, although this is not certain (Lias to Recent). It is present in existing oceans in bottom oozes from many localities and at various depths.

GLOBIGERINA CRETACEA d'Orbigny.

Pl. VIII, fig. 1.

Globigerina cretacea d'Orbigny, 1840, Mém. Soc. Géol. France, vol. 4, p. 34, pl. iii, figs. 12–14.

Globigerina cretacea Brady, 1879, Quart. Jour. Microsc. Sci., new series, vol. 19, p. 285.

Globigerina cretacea Brady, 1884, Challenger Report, vol. 9, pp. 596, 597, pl. lxxxii, fig. 10a–c. (Fossil form fig. 11.)

Globigerina cretacea Bagg, 1898, Bull. U. S. Geol. Survey No. 88, p. 64.

Test rotaliform, but strongly depressed; superior surface flattened or but slightly convex, inferior side depressed toward the center and excavated at the umbilicus; periphery obtuse and lobulated; shell consisting of from five to seven segments, the latter relatively small, subglobular aperture opening into the umbilical vestibule. Diameter less than 1 mm. Geological range is from Cretaceous to Recent.

In the California Miocene *Globigerina bulloides* is extremely common. *Globigerina dubia* is also numerous, but typical specimens of *Globigerina cretacea* are hard to find. There are undoubtedly present better specimens than the writer could obtain by boiling the marl, but

a number of perfect forms were obtained of *Globigerinæ* by collecting the forms which float and drying them on a cloth by straining the water.

GLOBIGERINA DUBIA Egger.

Pl. VIII, fig. 2.

Globigerina dubia Egger, 1857, Neues Jahrb. für Min., Geol., Pal., p. 281, pl. ix, figs. 7–9.
Globigerina dubia Brady, 1879, Quart. Jour. Microsc. Sci., new series, vol. 19, p. 71.
Globigerina dubia Brady, 1884, Challenger Report, vol. 9, pp. 595, 596, pl. lxxix, fig. 17.
Globigerina dubia Egger, 1895, Jahrsber. Naturhist. Ver. Passau, vol. 16, p. 37, pl. iv, fig. 17.

"Test rotaliform, subglobular, somewhat compressed; margin rounded and lobulated; inferior umbilicus large and deeply sunk; composed of about three convolutions, the outermost of which consists of five or six relatively small, inflated segments; the apertures of the chambers opening directly into the umbilical vestibule. Diameter often nearly one thirty-fifth of an inch (0.73 mm.)."[a]

This species is rather common in the California material though less frequent than *Globigerina bulloides*. The specimens are much larger than the latter species, are more stoutly built, and the pores of the cell walls are larger and coarser. Its geological range is apparently confined to the later Tertiary and Recent period and the writer has no record of its occurring in the Eocene. The present range of the species is also limited, and while it occupies bottom oozes it is by no means widely diffused or as abundant as many of its congenitors.

Genus ORBULINA d'Orbigny (1839).

ORBULINA UNIVERSA d'Orbigny.

Pl. VIII, fig. 3.

Orbulina universa d'Orbigny, 1839, Foram. Cuba, p. 3, pl. i, fig. 1.
Orbulina universa d'Orbigny, 1839, Foram. Canaries, p. 122, pl. i, fig. 1.
Orbulina universa Brady, 1884, Challenger Report, vol. 9, pp. 608, 609, pl. lxxviii; pl. lxxxi, figs. 8–26; pl. lxxxii, figs. 1–3.
Orbulina universa Egger, 1895, Jahrsber. Naturhist. Ver. Passau, vol. 16, p. 38, pl. iv, figs. 18, 19.

Test globular or nearly so, composed of only one chamber, or perhaps in variable types two indistinct chambers, or of one chamber inclosing a polythalamous, globigerina-like shell, which in recent specimens can be seen occasionally through the transparent hyaline walls of the outer enveloping chamber. This outer chamber is frequently spinous, though these spines are absent apparently in fossil forms and perhaps are broken off, although it is not certain that they are always

[a] Brady, Challenger Report, vol. 9, 1884, p. 595.

present. There is a roughness about the outer surface which may represent these spinous markings in recent forms, but they are so minute that it is doubtful if this character is of value in determination of the species and if it is constantly a characteristic. There seems to be a marked difference in the size of the shell, but on an average good specimens measure about 0.15 mm. in diameter. The test is often broken and it is possible that some of the single-shell chambers seen in the washed marl are fragments of *Globigerina*, but in some almost perfectly globular forms there can be no question but that this species is present in rather considerable abundance. The species first occurs in the Lias (Terquem), and it is found in the Jurassic limestones of Switzerland (Haeusler), in the chalk of the island of Rugen, and at Volsk, Russia (Reuss), in Septaria clays and upper Oligocene of Germany (Reuss), in the Miocene of Vienna (d'Orbigny), in the later Tertiaries of Italy (Costa, Terrigi, etc.), and elsewhere. It is the commonest of all pelagic Foraminifera to-day and is known in bottom specimens and surface dredgings at every depth and in all latitudes.

Genus PULLENIA Parker and Jones (1862).

PULLENIA SPHÆROIDES (d'Orbigny).

Pl. VIII, fig. 4.

Nonionina sphæroides d'Orbigny, 1826, Annales Sciences Naturelles, vol. 7, p. 293, No. 1, Modèle, No. 43.

Pullenia sphæroides Carpenter, 1862, Introd. Study Foram., p. 184, pl. xii, fig. 12.

Pullenia sphæroides Brady, 1884, Challenger Report, vol. 9, pp. 615, 616, pl. lxxxiv, figs. 12, 13, and cut in text, p. 616, fig. 18.

Pullenia sphæroides Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 252, pl. xxx, fig. 6.

Chapman reports this species as frequent in the California Miocene of Santa Clara County. It appears to be very rare in the material the writer investigated. The species in its outer appearance resembles the thick forms of the genus *Nonionina*. It is, as its name implies, nearly spheroidal in outline, but is slightly compressed at the umbilici. The few large outer segments, five or six in number, completely envelope the earlier chambers. Surface of shell smooth, glistening. The test is finely perforate, much more so than in *Globigerinæ*. Professor Brady stated in the Challenger Report that these pores do not exceed 0.001 mm. in diameter. The septal lines are only faintly indicated on the exterior surface and are not depressed in the slightest, but they can be seen in reflected light and appear as nearly straight lines running to the shell margin. The septal face is very narrow, very broadly oval, and the aperture occurs as a long cavity extending nearly the entire width of the shell upon the inner margin of the final segment. Cross sections show three or four convolutions.

Geologically the species is found from Cretaceous to Recent. In existing oceans *Pullenia sphæroides* is widely distributed both areally and bathymetrically, since it is found from a few fathoms down to nearly 3,000 fathoms. It has been described from many Tertiary deposits where the species seems to have its greatest development.

Family ROTALIDÆ.

Subfamily ROTALINÆ.

Genus DISCORBINA Parker and Jones (1862).

DISCORBINA ALLOMORPHINOIDES (Reuss).

Pl. VIII, fig. 5.

Valvulina allomorphinoides Reuss, 1860, Sitzungsber. K. Akad. Wiss. Wien, vol. 40, p. 223, pl. xi, fig. 6.

Discorbina allomorphinoides Brady, 1884, Challenger Report, vol. 9, p. 654, pl. xci, figs. 5, 8.

Discorbina allomorphinoides Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 253, pl. xxx. fig. 8.

The *Challenger* expedition (Brady) reports the finding of this species at three stations—at a depth of 10 fathoms off Port Jackson, at 155 fathoms off Raine Island, and at 95 fathoms off the Philippines. Reuss's specimens were from the Cretaceous of Westphalia.

Test discoidal, thick, built of a few massive chambers, six or seven in the final convolution, separated by nearly straight depressed septa. Ultimate chamber much the largest, with the opening under the margin upon the inferior side. Chapman reports the species as very abundant. The author finds numerous examples also in the material studied.

Genus TRUNCATULINA d'Orbigny (1826).

TRUNCATULINA PYGMÆA Hantken.

Pl. VIII, fig. 6.

Truncatulina pygmæa Hantken, 1875, Mitth. K. ung. geol. Anstalt, vol. 4, p. 78, pl. x, fig. 8.

Truncatulina pygmæa Brady, 1884, Challenger Report, vol. 9, pp. 666, 667, pl. xcv, figs. 9, 10.

Truncatulina pygmæa Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 254, pl. xxx, fig. 11.

The test of *Truncatulina pygmæa* is circular, vaulted on both sides, with nine or ten chambers in the final volution separated by slightly arched septa on the inferior surface. On the superior side there are a few more chambers in the final volution separated by curving septa and with from two and a half to three convolutions, all of which are seen on the superior aspect. The shell is rather common in the Cali-

fornia Miocene. As a fossil it was recorded by Hantken from the Oligocene of Hungary. In existing seas it is rare and is essentially a deep-water foraminifer.

TRUNCATULINA LOBATULA (Walker and Jacob).

Pl. IX, fig. 1.

Nautilus lobatulus Walker and Jacob, 1798, Adam's Essays, Kanmacher's ed., p. 642, pl. xiv, fig. 36.

Truncatulina lobatula Brady, 1884, Challenger Report, vol. 9, pp. 660, 661, pl. xcii, fig. 10; pl. xciii, figs. 1, 4, 5; pl. cxv, figs. 4, 5.

Truncatulina lobatula Egger, 1895, Jahrsber. Naturhist. Ver. Passau, vol. 16, p. 31, pl. v, fig. 5, a, b, c.

Truncatulina lobatula Bagg, 1898, Bull. U. S. Geol. Survey No. 88, p. 65.

The species designated *Truncatulina lobatula* is probably as widely diffused as *Globigerina bulloides* which is known in every ocean, in every sea, and at all depths. The earliest record of the form as a fossil is in carboniferous strata and it is well known in every subsequent deposit.

The characteristic features of this very variable species are its plano-convex habit; only moderately vaulted on the inferior surface; last volution with from six to eight chambers, separated by very slightly depressed septa which are more arcuate upon the superior surface and more nearly straight upon the lower or vaulted side. The aperture is typically located in an extended cavernous slit at and along the inner margin of the ultimate segment upon the superior surface.

The varieties of the species are interminable and some are sessile as in fig. 10, pl. xcii, of the Challenger Report. The more convex varieties merge into *Truncatulina refulgens* and the flattened varieties constitute *Truncatulina wuellerstorfi*. Regular built forms comprise the species *Truncatulina boueana* d'Orbigny, while irregular wide-growing specimens belong under *Truncatulina variabilis* d'Orbigny. The specimens are very coarsely porous in California, and are not very frequent considering the large amount of material examined.

TRUNCATULINA VARIABILIS d'Orbigny.

Pl. IX, fig. 2.

Truncatulina variabilis d'Orbigny, 1826, Annales Sciences Naturelles, vol. 7, No. 8, p. 279.

Truncatulina variabilis Terquem, 1878, Mém. Soc. Géol. France, sér. 3, vol. 1, mém. 3, p. 20, pl. i, figs. 18–25.

Truncatulina variabilis Brady, 1884, Challenger Report, vol. 9, pp. 661, 662, pl. xciii, figs. 6, 7.

D'Orbigny groups about twenty plates of Soldani's figures in his Testaceographia under the single species *Truncatulina variabilis*. There are probably no two of these wide-growing, flattened *Truncatu-*

lina exactly alike, but the general features of irregular chambers are similar. The California Miocene furnishes two or three forms which seem to belong here. The species is a shallow-water form and only in one instance was a specimen dredged from 2,000 fathoms. Usually it is present in shallow margins of tropical and temperate seas. It has been found in the Eocene of Paris basin, and is known throughout the later Tertiaries. The California specimens are broken at the ultimate segment. The portion remaining measures in short diameter 0.9 mm.

TRUNCATULINA WUELLERSTORFI (Schwager).

Pl. IX, fig. 3.

Anomalina wuellerstorfi Schwager, 1866, Novara-Exped., Geol., vol. 2, p. 258, pl. vii, figs. 105, 107.

Truncatulina wuellerstorfi Brady, 1884, Challenger Report, vol. 9, p. 662, pl. xciii, figs. 8, 9.

Truncatulina wuellerstorfi Uhlig, 1886, Jahrb. K.-k. geol. Reichsanstalt, vol. 36, p. 174, fig. 3.

Truncatulina wuellerstorfi (*wuellerstorfii*) Egger, 1895, Jahrsber. Naturhist. Ver. Passau, vol. 16, p. 31, pl. v, fig. 6 a, b, c.

Truncatulina wuellerstorfi Bagg, 1898, Bull. U. S. Geol. Survey No. 88, p. 66.

Test circular, coarsely porous; inferior surface convex, superior complanate; peripheral edge acute; chambers narrow; septa strongly curved, crescent-shaped with broad septal ridges, nine in the last convolution; aperture a small marginal slit. The specimens the writer obtained in the New Jersey Cretaceous measured 0.5 mm. in diameter. These specimens were much more vaulted than the typical forms, while the specimens (not common) in the California strata are very strongly depressed and are typical for the species. The pores are remarkably large and coarse. The form occupies an intermediate position between *Truncatulina lobatula* and *Anomalina arimensis*.

The species is known as early as the Cretaceous (Bagg); is reported from the Pliocene of Kar Nicobar (Schwager), but is not abundantly noted in fossil strata. In the deep-water oozes of existing seas *Truncatulina wuellerstorfi* is frequently present and it has been dredged from about 200 to over 2,000 fathoms.

Genus ANOMALINA d'Orbigny (1826).

ANOMALINA AMMONOIDES (Reuss).

Pl. IX, fig. 4.

Rosalina ammonoides Reuss, 1845, Verstein. böhm. Kreid., pt. 1, p. 36, pl. xiii, fig. 66; pl. viii, fig. 53.

Rotalia ammonoides Gümbel, 1870, Sitzungsber. K. bayer. Akad. Wiss., p. 283.

Planorbulina ammonoides Jones and Parker, 1872, Quart. Jour. Geol. Soc. London, vol. 28, p. 106; table, p. 109.

Anomalina ammonoides Brady, 1884 Challenger Report, vol. 9, pp. 672, 673, pl. xciv, fig. 2, 3.

Anomalina ammonoides Bagg, 1898, Bull. U. S. Geol. Survey No. 88, p. 67, pl. vi, fig. 5.

Test nautiloid, coarsely porous, small, compressed; lateral surfaces nearly equally convex; depressed at the umbilici. The peripheral margin is round and the aperture is a nearly median arched slit upon the inner margin of the ultimate segment. The diameter measures from 0.5 to 0.8 mm.

Geological distribution is from Cretaceous to Recent. The *Challenger* dredged only one station in the North Atlantic which yielded the above species from a depth of 435 fathoms. In the South Pacific many dredgings from a few fathoms to 1,350 furnished specimens and the species is widely distributed, being found in the Red Sea, off Bombay, Hongkong, New Zealand, Humboldt Bay, Papua, and in shore sands from Melbourne.

ANOMALINA ARIMINENSIS (d'Orbigny).

Pl. IX, fig. 5.

Planulina ariminensis d'Orbigny, 1826, Annales Sciences Naturelles, vol. 7, p. 280, pl. v, figs. 1–3, bis; Modèle No. 49.

Planorbulina ariminensis Parker, Jones and Brady, 1865, Ann. Mag. Nat. Hist., ser. 3, vol. 16, p. 26, pl. iii, fig. 78.

Anomalina ariminensis Brady, 1884, Challenger Report, vol. 9, pp. 674, 675, pl. xciii, figs. 10, 11.

Test perfectly complanate or nearly so, sides flat, periphery nearly square, sutures deeply incised, septa curved, aperture nearly median. The shell closely resembles *Anomalina ammonoides*, but is much more depressed. Its nearest isomorph is *Discorbina biconcava*, Parker and Jones. It appears first as a fossil in the chalk of England, and is present in succeeding formations down to the present time. In the North Atlantic it is widely distributed and ranges from 150 to 1,600 fathoms. Two localities in the South Atlantic yielded specimens at depths of 350 and 2,200 fathoms. At the greater depth specimens were rare, the species being more abundant at the lesser depth and of typical forms. It is common in the Mediterranean at every depth down to 500 fathoms. Parker and Jones detected it in material from the Abrolhos Bank at a depth from 47 to 940 fathoms. It is rare in the California Miocene. Diameter, short axis, 0.5 mm.

ANOMALINA GROSSERUGOSA (Gümbel).

Pl. IX, fig. 6.

Truncatulina grosserugosa Gümbel, 1868, Abhandl. m.-ph. Cl. K. bayer. Akad. Wiss., vol. 10, p. 660, pl. ii, fig. 104 a, b.

Truncatulina grosserugosa Hantken, 1875, Mittheil. K. ung. geol. Anstalt, vol. 4, p. 74, pl. ix, fig. 6, a, b

Anomalina grosserugosa Brady, 1884, Challenger Report, vol. 9, p. 673, pl. xciv, figs. 4, 5.

Anomalina grosserugosa Bagg, 1898, Bull. U. S. Geol. Survey No. 88, p. 67, pl. vi, fig. 4.

Anomalina grosserugosa Sherborn and Chapman, 1889, Jour. Roy. Microsc. Soc., p. 487, pl. xi, fig. 34.

Anomalina grosserugosa Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 1, pp. 253, 254, pl. xxx, fig. 9.

Test nautiloid, very coarsely porous, pores larger and more numerous upon the inferior surface; both sides convex; umbilici distinct; peripheral margin round; chambers large, inflated, only eight in final convolution; septa nearly straight; aperture median or nearly so, arched. The form is closely related to *Nonionina umbilicatula*, but its chambers are more strongly inflated and the pores are larger. It is also very closely related to *Anomalina ammonoides*, but there are a much smaller number of chambers in the former, and the form is more massive and the volutions are not so distinct as in *A. ammonoides*.

The geological distribution begins with the upper Cretaceous (Bagg), and the species is found in the Eocene of Bavaria (Gümbel), the Clavulina-szaboi formation of Hungary (Hantken), the Miocene of Vienna (d'Orbigny). It seems to be a rather abundant species in the Tertiary. In existing oceans, Professor Brady noted its occurrence at four stations in the North Atlantic at depths ranging from 450 to 1,000 fathoms; at three stations in the South Atlantic at depths ranging from 420 to 1,415 fathoms; at two in the South Pacific at depths of 610 and 2,160 fathoms, and at two in the North Pacific at depths of 345 and 2,050 fathoms.

ANOMALINA ROTULA d'Orbigny.

Pl. X, fig. 1.

Anomalina rotula d'Orbigny, 1846, Foram. Foss. Vienne, p. 172, pl. x, figs. 10–12.

Planorbulina rotula Sherborn and Chapman, 1886, Jour. Roy. Microsc. Soc., ser. 2, vol. 6, p. 757, cut in text No. 155.

Planorbulina rotula Terrigi, 1889, Mem. R. Accad. Lincei, ser. 4, vol. 6, p. 116, pl. vii, fig. 4.

Anomalina rotula Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 254, pl. xxx, fig. 10.

The test of *Anomalina rotula* represents the extreme variation from the symmetrical form of the genus being closely allied with Planorbuline types. The entire convolutions are visible upon one side, and reveal about twenty-two chambers, of which nine or ten constitute the last volution. The aperture is nearly median as in normal species, and the reverse side is umbilicated, and the margin is neatly rounded. The shell is very abundant in the California Miocene. Its earliest appearance is from the Eocene, and it appears to be limited to the Tertiary.

Genus PULVINULINA Parker and Jones (1862).

PULVINULINA AURICULA (Fichtel and Moll).

Pl. X, fig. 3.

Nautilus auricula var. a. Fichtel and Moll, 1803, Test. Microsc., p. 108, pl. xx, figs. a, b, c.

Valvulina excavata d'Orbigny, 1839, Foram. Canaries, p. 137, pl. i, figs. 43–45.

Pulvinulina auricula, Brady, 1884, Challenger Report, vol. 9, pp. 688, 689, pl. cvi, fig. 5, a, b, c.

The test of *Pulvinulina auricula* is elongate-oval, with rather square-set anterior margin made by prolongation of the ultimate chamber. There is scarcely any difference between the vaulting of each side, but if anything the superior is the lower of the two. The form resembles *P. brongniartii*, already described in this report, but it is only one-half the size (0.3 mm.), is much whiter, cleaner, more delicate, and appears to possess fully as sharp a keel as the more pronounced acute-margined forms of the species. Only a few specimens of this species are present. The geological distribution of *Pulvinulina auricula* commences with the Eocene and extends to the present day. It has been described under many synonyms and has been placed under several genera, such as *Rotalina*, *Valvulina*, *Nautilus*, etc. The bathymetric range of the species in the North Atlantic, where it is most common, is from the littoral zone down to 200 fathoms, and specimens have been dredged at over 500 fathoms, but the form is typically a shallow-water species.

PULVINULINA BRONGNIARTII (d'Orbigny).

Pl. X, fig. 2.

Rotalia brongniartii d'Orbigny, 1826, Annales Sciences Naturelles, vol. 7, p. 273, No. 27.

Rotalina brongniarti Reuss, 1845–46, in Geinitz, Grundr. Verstein., p. 673, pl. xxiv, fig. 55.

Rotalina bromgniartii d'Orbigny, 1846, Foram. Foss. Vienne, pp. 158, 159, pl. viii, figs. 23–24.

Pulvinulina brogniarti (*brongniartii*) Hantken, 1875 (1876), A magy. kir. foldt. int. evkonyve, vol. 4, p. 68, pl. ix, fig. 5.

Test similar to typical "*auricula*" *Pulvinulina* forms with obliquely set chambers on the superior surface and with nearly straight depressed septa on the inferior side. The margin terminates in sharp obtuse-angled periphery and both surfaces are vaulted with the ultimate chamber so much enlarged as to give an unsymmetrical appearance when the shell is viewed from the anterior aspect. D'Orbigny considered the species closely related to *Rotalina elliptica*, from which it is distinguished by its more elliptical form and its less rugose character. The form *Pulvinulina brongniartii* appears to be very closely related to *Pulvinulina oblonga*, but the latter has curved septa and more

numerous chambers on its superior surface. It also resembles *Pulvinulina auricula*, but the latter has a somewhat greater quadrangular elongation.

It is barely possible that the species under discussion may be considered a variety of the more commonly described species *Pulvinulina auricula*. D'Orbigny's specimens were from the Miocene of Nussdorf and from Baden, Austria, and he states that it is living in the Adriatic Sea.

Genus ROTALIA (Lamarck), 1804.

ROTALIA BECCARII (Linné).

Pl. X, fig. 4.

Nautilus beccarii Linné, 1767, Syst. Nat., 12th ed., p. 1162; 1788, Gmelin's ed., p. 3370, No. 4.

Streblus beccarii Fischer, 1819, Adversaria Zoologica, fasc. ii, p. 75.

Turbinulina beccarii d'Orbigny, 1826, Annales Sciences Naturelles, vol. 7, p. 275, No. 42; Modèle No. 74.

Rotalia beccarii (sp. *becarii*) Brown, 1844, Illustr. Recent Conch. Great Britain, ed. 2, p. i, pl. i, fig. 12.

Rotalia beccarii Brady, 1884, Challenger Report, vol. 9, p. 704, pl. cvii, figs. 2, 3.

Rotalia beccarii Bagg, 1898, Bull. American Paleont., vol. 2, No. 10, p. 38, pl. iii, fig. 3.

Test finely porous, formed of a nearly circular low turbinate spire with an obtusely rounded, lobulated peripheral margin. The test is composed of three or four convolutions compactly built, and with a large number of chambers which are separated from one another by highly curved septa. The inferior surface is often beaded by exogenous granules at or near the umbilicus. As a fossil the form first occurs in the Miocene and it is known in the later Tertiaries in many regions. It is very abundant in the Pleistocene of Cornfield Harbor, Md., and was found by the writer in the Miocene of Darlington, S. C. It is a shallow-water foraminifer, and according to Professor Brady it inhabits the margins of all great oceans.

ROTALIA SOLDANII (d'Orbigny).

Pl. X, fig. 5.

Gyroidina soldanii d'Orbigny, 1826, Annales Sciences Naturelles, vol. 7, p. 278, No. 5, Modèle No. 36.

Rotalia soldanii (after d'Orbigny) Parker, Jones, and Brady, 1871, Ann. Mag. Nat. Hist., ser. 4, vol. 8, p. 176, pl. xii, fig. 151.

Rotalia soldanii Brady, 1884, Challenger Report, vol. 9, pp. 706, 707, pl. cvii, figs. 6, 7.

Rotalina soldanii Egger, 1895, Jahrsber. Naturhist. Ver. Passau, vol. 16, p. 34, pl. v, fig. 10.

Rotalia soldanii Bagg, 1898, Bull. American Paleont., vol. 2, No. 10, p. 333.

Test plano-convex or nearly so, circular, and with slightly lobulated periphery, superior side showing numerous curved septa, inferior side

much vaulted, with approximately straight septa which are excavated at the umbilicus.

"The plano-convex habit of growth reaches its extreme development, so far as the present genus is concerned, in *Rotalia soldanii*, the test of which resembles that of *Rotalia orbicularis*, except that the convexity of the inferior side is considerably greater. The species corresponds morphologically to *Truncatulina refulgens* and *Truncatulina micheliniana*, but the shell is more neatly and compactly built, the outline is more rounded, and the walls more finely perforated than in either of the latter species. Sections of the test show that the septal walls are double, and that there is a considerable deposit of shell substance in the region of the umbilicus, but without any trace of canals."[a]

The species is known as far back as the Cretaceous, and is present in every succeeding formation. In existing oceans it is universally distributed in deep waters, and is seldom found at depths of less than 300 fathoms. The California Miocene contains only a few specimens of this species.

Family NUMMULINIDÆ.

Subfamily POLYSTOMELLINÆ.

Genus NONIONINA d'Orbigny (1826).

NONIONINA POMPILIOIDES (Fichtel and Moll).

Pl. X, fig. 6.

Nautilus pompilioides Fichtel and Moll, 1798, Test. Brit., p. 31, pl. ii, figs. a–e.
Nonionina umbilicatula d'Orbigny, 1826, Annales Sciences Naturelles, vol. 7, p. 293, pl. xv, figs. 10–12, No. 5, Modèle No. 86.
Nonionina pompilioides Parker, Jones, and Brady, 1871, Ann. Mag. Nat. Hist., ser. 4, vol. 8, p. 246, pl. xii, fig. 158.
Nonionina pompilioides Brady, Challenger Report, 1884, vol. 9, p. 727, pl. cix, figs. 10, 11.
Nonionina pompilioides Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 256, pl. xxx, figs. 16, 16a.

The test of *Nonionina pompilioides* is characterized by a few large, thick, closely involuted chambers, the ultimate of which ends in a broad, flat, terminal septal face. Most of our forms have six chambers visible in the final volution. The septa are straight, or nearly so, and the aperture is a centrally placed slit upon the inner side of the ultimate chamber. The form resembles *Nonionina umbilicatula*, but the form is thicker, has fewer chambers, and is of smaller diameter. At the present time it seems to be almost exclusively a deep-water form, and in the Challenger Report it is recognized from seven stations in

[a] Challenger Report, vol. 9, pp. 706, 707.

the North Atlantic at from 1,000 to 2,750 fathoms; from one in the South Atlantic at 2,200 fathoms; from two in the Southern Ocean at 1,570 and 1,950 fathoms; from eight in the South Pacific Ocean from 1,350 to 2,421 fathoms; and from two in the North Pacific from 1,850 and 2,250 fathoms. Its geological distribution begins with the middle Tertiary.

Mr. Chapman recognizes it as a rare form in the Miocene of Santa Clara County, Cal. It is present in the present collection, and is common.

NONIONINA BOUEANA d'Orbigny.

Pl. XI, fig. 1.

Nonionina boueana d'Orbigny, 1846, Foram. Foss. Vienne, p. 108, pl. v., figs. 11, 12.
Nonionina boueana Brady, 1884, Challenger Report, vol. 9, p. 729, pl. cix, figs. 12, 13.
Nonionina boueana Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, pp. 255, 256, pl. xxx, figs. 14, 14a.

This beautiful species of *Nonionina* is rather rare in the material we are investigating, although Chapman reports that it is frequent in the California Miocene of Santa Clara County. The sutures are remarkably wide and gracefully curved with somewhat depressed umbo and with very sharp periphery, though without definite keel. The septal face is very long oval and with the slit-like aperture on the inner margin. There are about ten chambers in the final volution, the inner two are not easily distinguished and the outline of the shell is elongate-oval, due to lengthening of the ultimate chamber. This species has been recorded in several other places than those given above. The writer discovered it in the Miocene well-boring material from Norfolk, Va., and described it in the "Tertiary and Pleistocene Foraminifera of the Middle Atlantic Slope."[a] The small diameter of the shell measures 0.35 mm. The geological range is from the Oligocene to Recent. There are seven localities mentioned by Brady in the Challenger Report where this species was found, but in every case the shells were in very shoal waters, the deepest being in the Bay of Biscay, at a depth of 200 fathoms.

NONIONINA COMMUNIS d'Orbigny.

Pl. XI, fig. 2.

Nonionina communis d'Orbigny, 1826, Annales Sciences Naturelles, vol. 7, p. 294, No. 20.
Nonionina communis d'Orbigny, 1846, Foram. Foss. Vienne, p. 106, pl. v, figs. 7, 8.
Nonionina communis Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 255, pl. xxx, fig. 13.

Mr. Chapman records this species as frequent in the Miocene of Santa Clara County, and it is not rare in the material of similar age

[a] Bull. American Paleont., vol. 2, No. 10, p. 334.

under investigation. The form occupies an intermediate position between *Nonionina scapha* and *Nonionina boueana*. The shell is composed of rapidly enlarging rather narrow chambers, of which the last is much the largest and longest, as in *N. scapha*. There are about eight or nine chambers visible in the final volution. Shell shows slightly depressed septa, but little arched, and the peripheral margin is broadly angular with a large oval septal face. The geological range is from Tertiary to Recent.

NONIONINA UMBILICATULA (Montagu).

Pl. XI, fig. 3.

Nautilus umbilicatulus Montagu, 1803, Test. Brit., p. 191; Suppl., p. 78, pl. xviii, fig. 1.
Robulina planciana d'Orbigny, 1826, Annales Sciences Naturelles, vol. 7, p. 290, No. 20.
Nonionina soldanii d'Orbigny, 1846, Foram. Foss. Vienne, p. 109, pl. v, figs. 15, 16.
Nonionina umbilicatula Terrigi, 1883, Atti Accad. Pontificia Nuovi Lincei, vol. 35, p. 203, pl. iv, fig. 48.
Nonionina umbilicatula Brady, 1884, Challenger Report, vol. 9, p. 726, pl. cix, figs. 8, 9.
Nonionina umbilicatula Chapman, 1900, Proc. California Acad. Sci., ser. 3, vol. 1, No. 8, p. 256, pl. xxx, fig. 15.

Test large and compactly built, with six or seven chambers in the outer volution, separated by nearly straight septa. The umbilicus is deeply sunken and the chambers increase rapidly in size and the ultimate segment ending in an oval almost globular septal face on the inner part of which is the elliptical aperture on the median plane. The shell is abundant in the California Miocene. It is closely related to *Nonionina depressula* and *Nonionina pompilioides*.

In existing oceans *Nonionina umbilicatula* is everywhere recognizable, and it is known in dredgings from as low as 30 to 3,125 fathoms. Its geological occurrence dates from the Eocene, and it has been recorded in every subsequent formation.

Genus POLYSTOMELLA Lamarck (1822).

POLYSTOMELLA CRISPA (Linné).

Pl. XI, fig. 4.

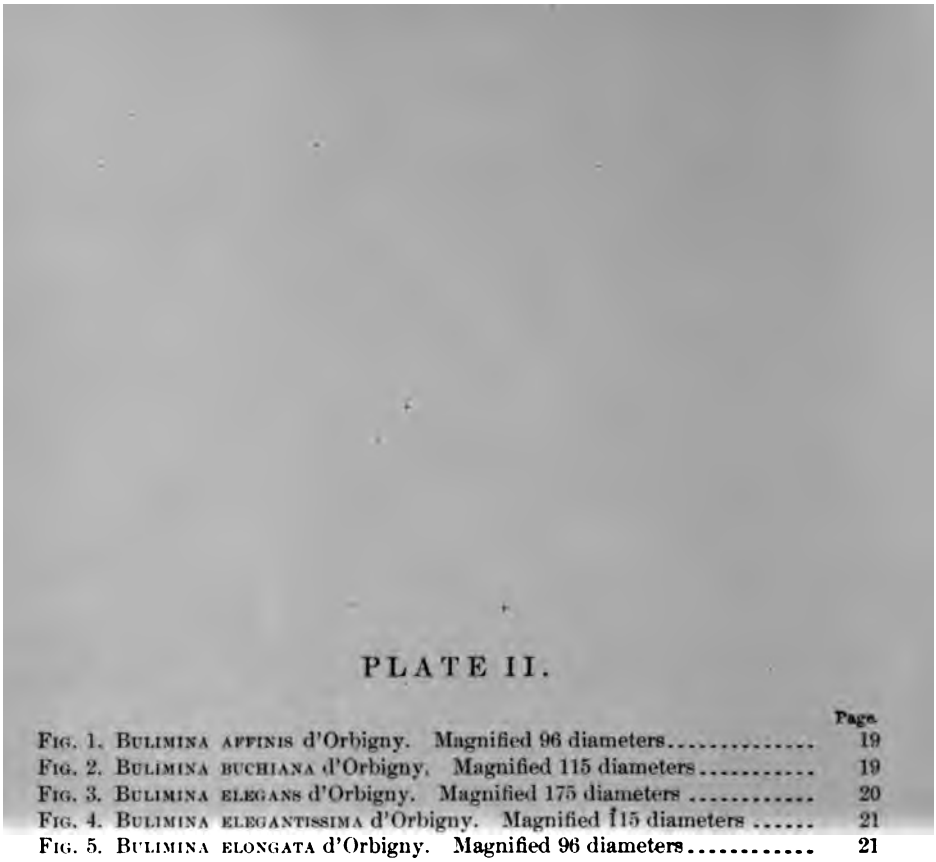
Nautilus crispus Linné, 1767, Syst. Nat., 12th ed., p. 1162; 275.
Polystomella crispa Lamarck, 1822, Anim. sans Vert., vol. 7, p. 625, No. 1.
Polystomella crispa d'Orbigny, 1846, Foram. Foss. Vienne, p. 125, pl. vi, figs. 9–14.
Polystomella crispa Williamson, 1858, Recent Foram. Great Britain, p. 40, pl. iii, figs. 78–80.
Polystomella crispa Brady, 1884, Challenger Report, vol. 9, p. 736, pl. cx, figs. 6, 7.

The species known as *Polystomella crispa* has been described by many authors in addition to the references given above. It is widely known in fossil beds from the Eocene, in the Septaria clays; in the Miocene of Germany, Austria, Bavaria, France, and Italy; it is also

described from the salt clay of Wieliczka by Reuss: from the Pliocene of Italy and Spain; from the Crag of England, and from the Quaternary of Europe. In existing oceans the species is abundant from a depth of a few fathoms down to 355 fathoms, and is known in arctic as well as tropical regions.

The shell is characterized by a moderately vaulted nautiloid biconvex test; sharp peripheral margin, well-defined umbo; numerous narrow, slightly curved chambers, separated by prominent septa, with broad septal bridges between them, which are not as numerous as the bridges in forms like *Polystomella craticulata* (Fichtel and Moll). The test is similar to *Polystomella macella* (Fichtel and Moll), but is not depressed at the umbo as in the latter species. The aperture consists of a V-shaped row of pores along the inner margin of the final segment. There is only one specimen in the California Miocene. Diameter, short axis, 0.5 mm.

PLATE II.



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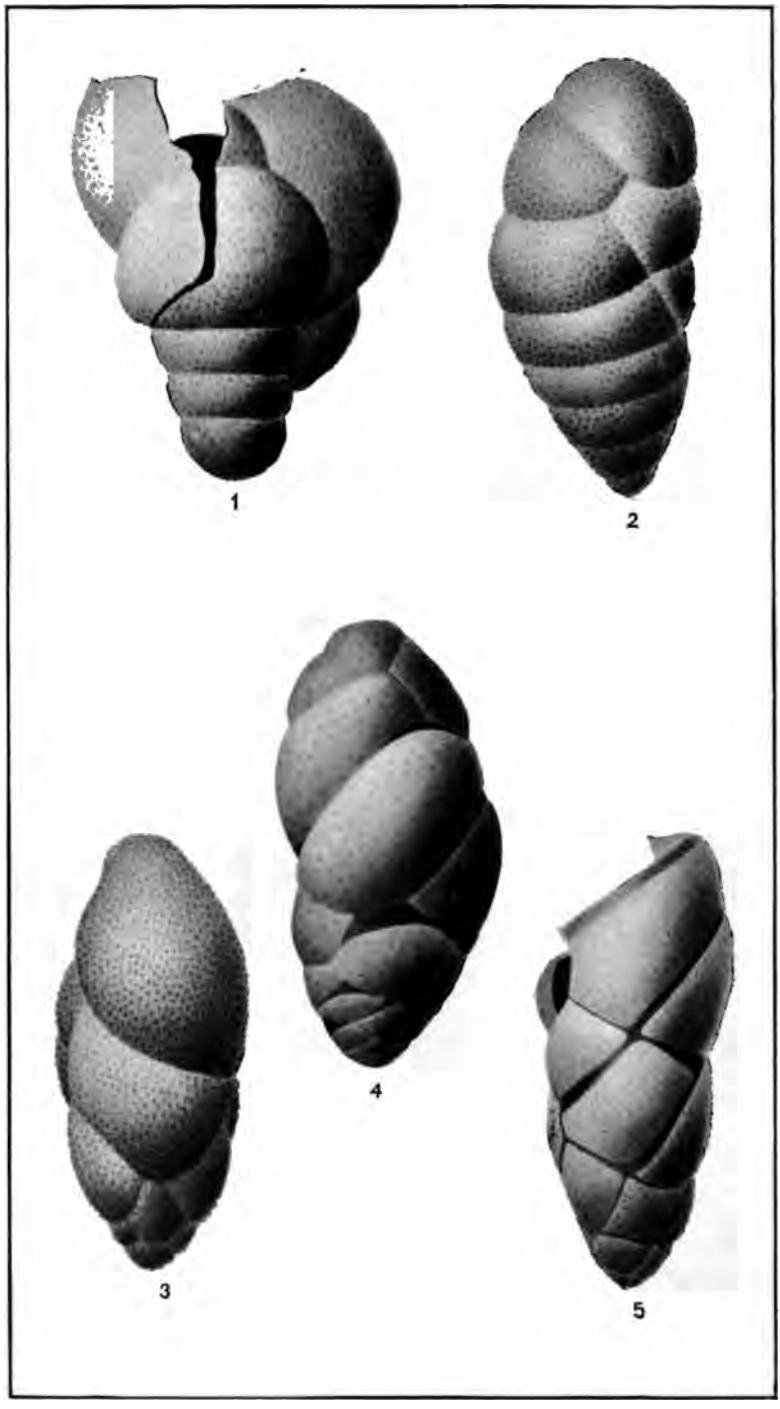

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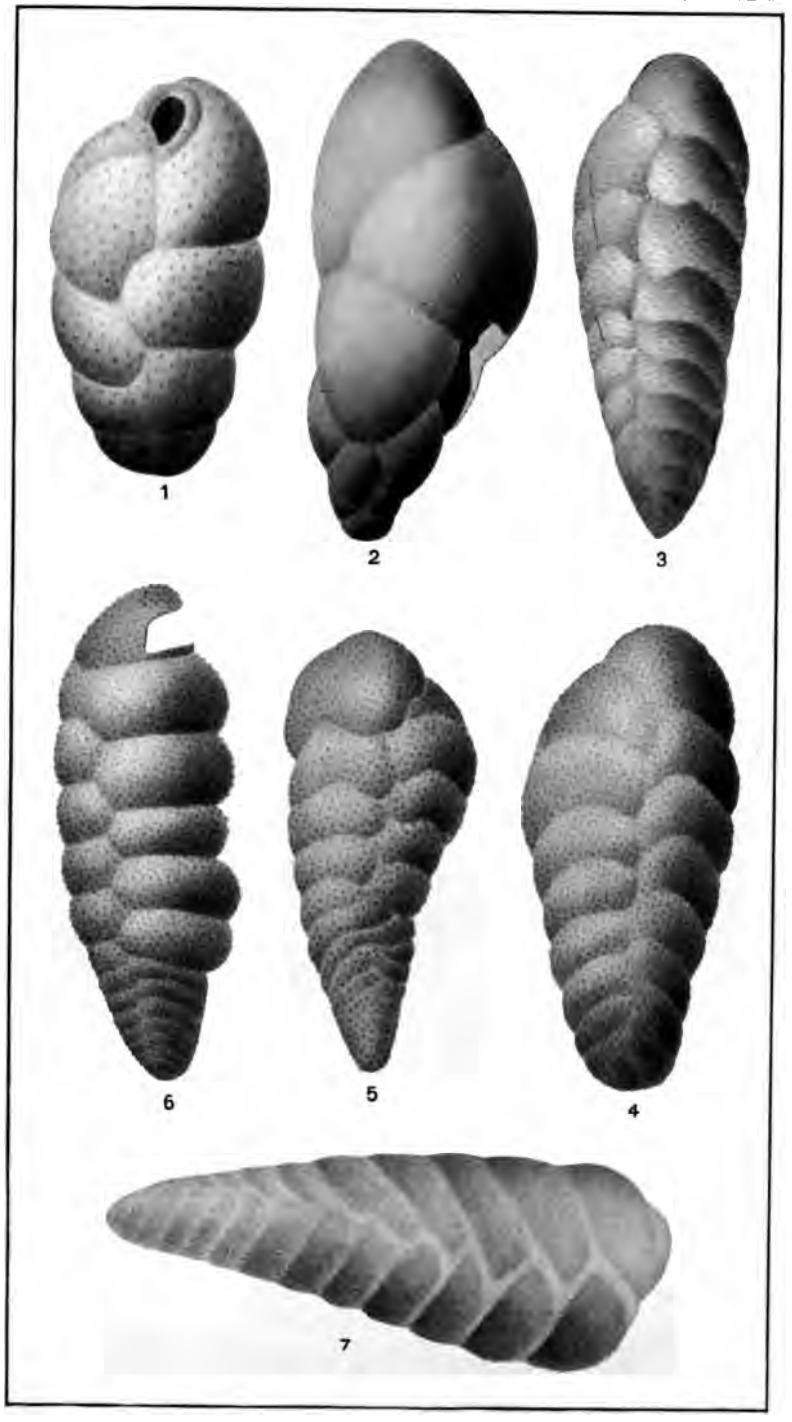

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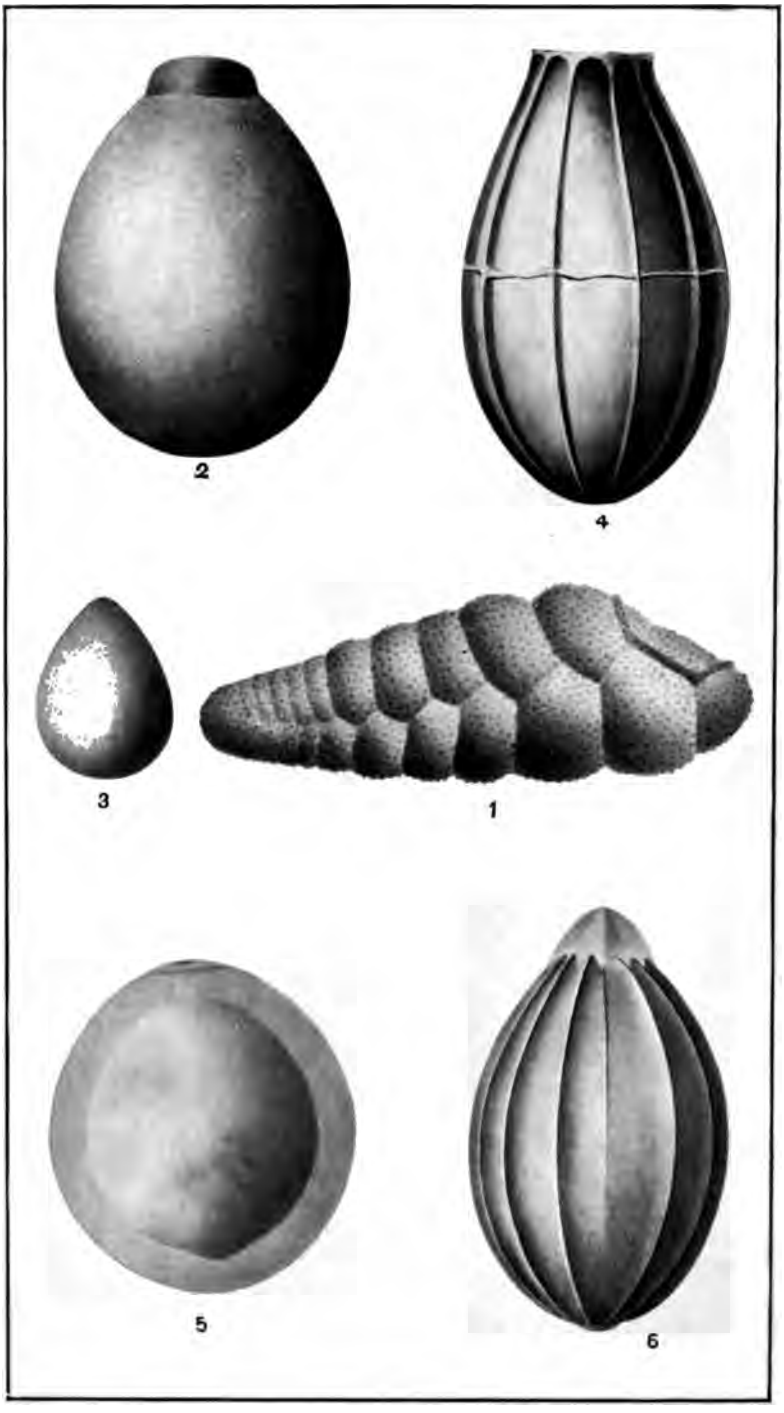

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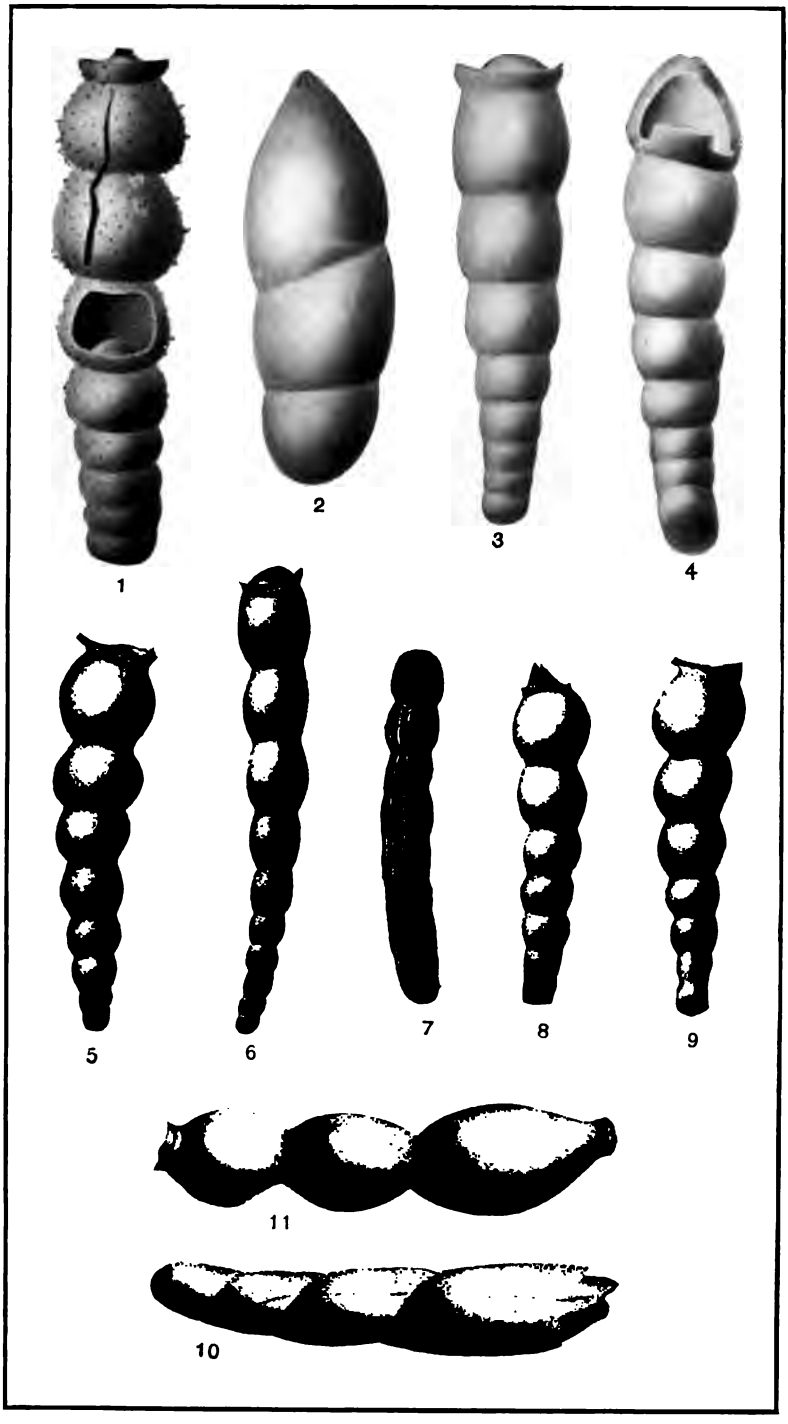

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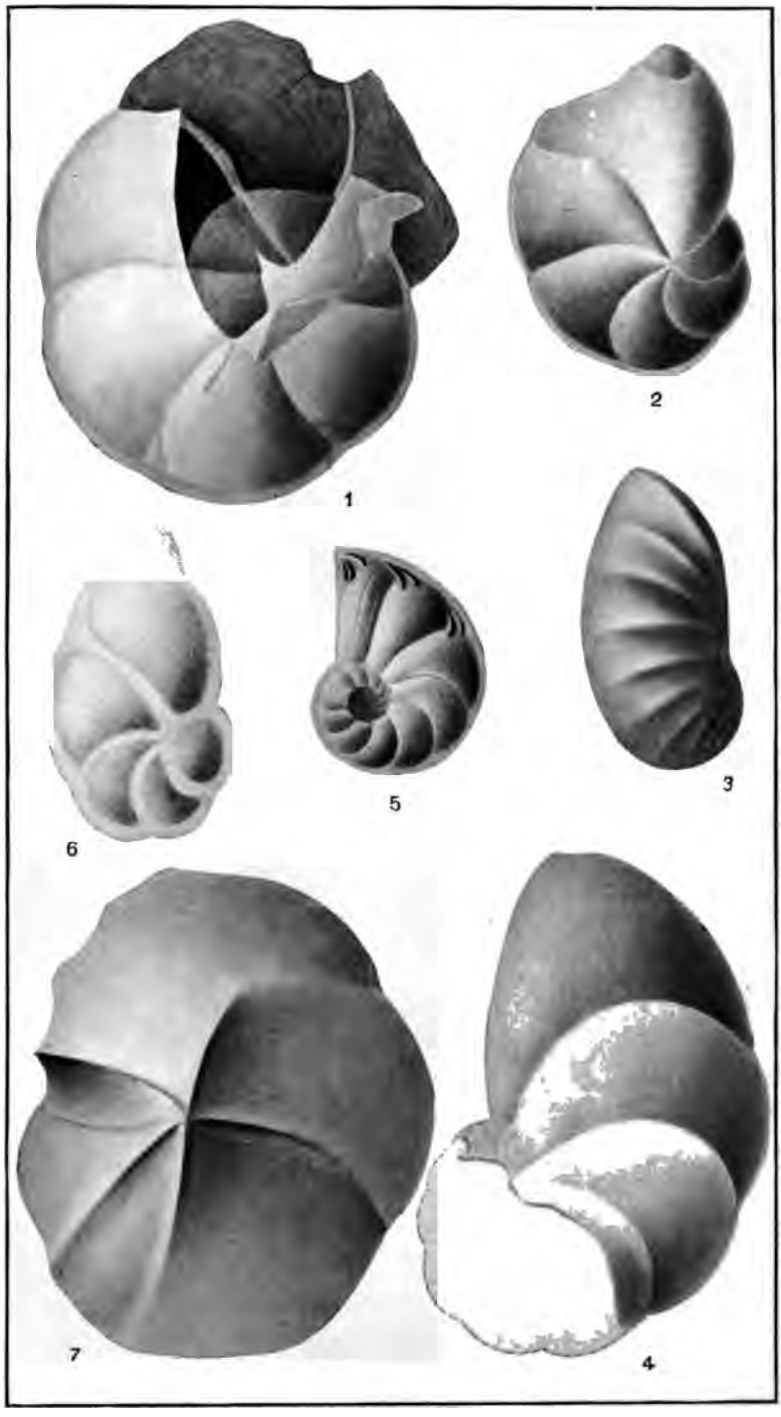

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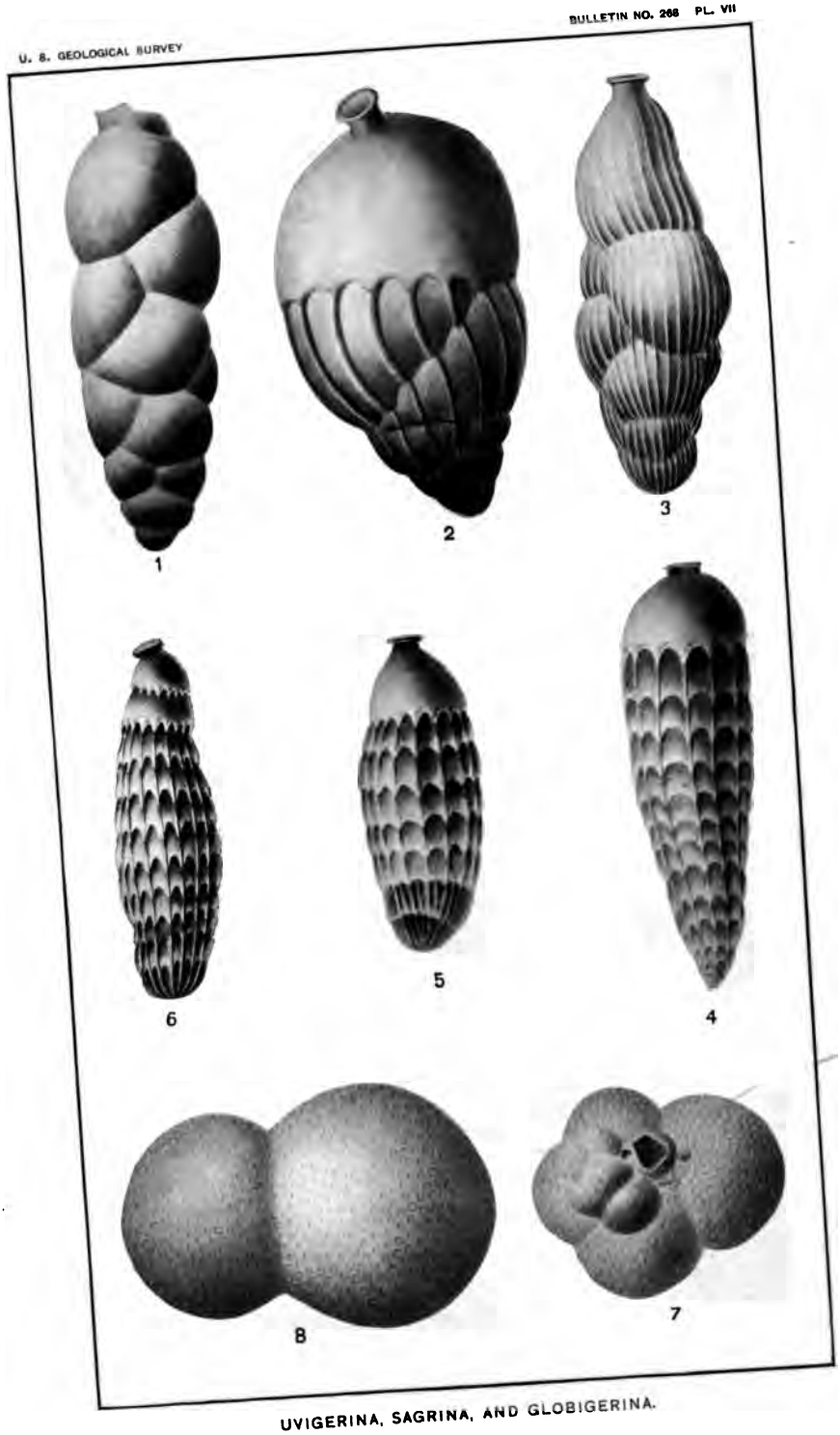

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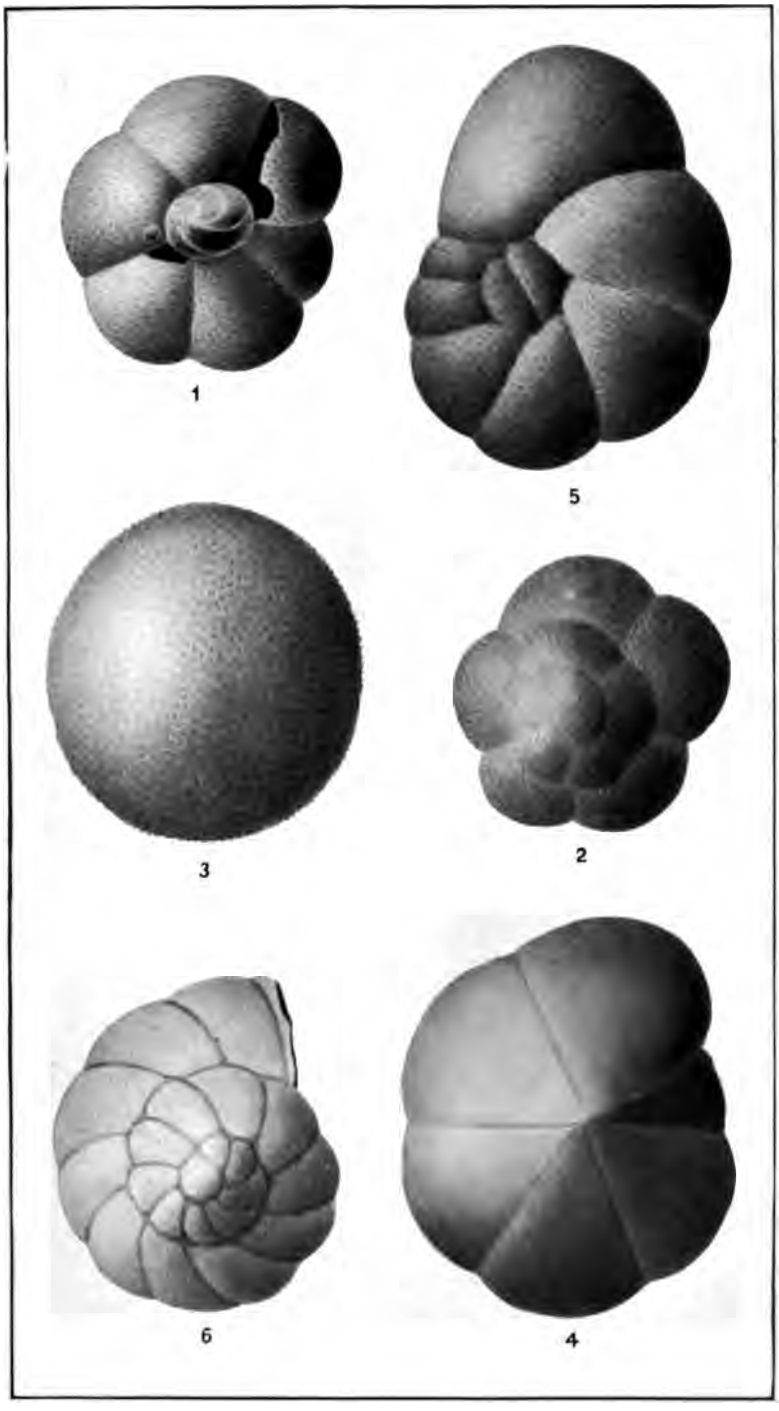

GLOBIGERINA, ORBULINA, PULLENIA, DISCORBINA, AND TRUNCATULINA.

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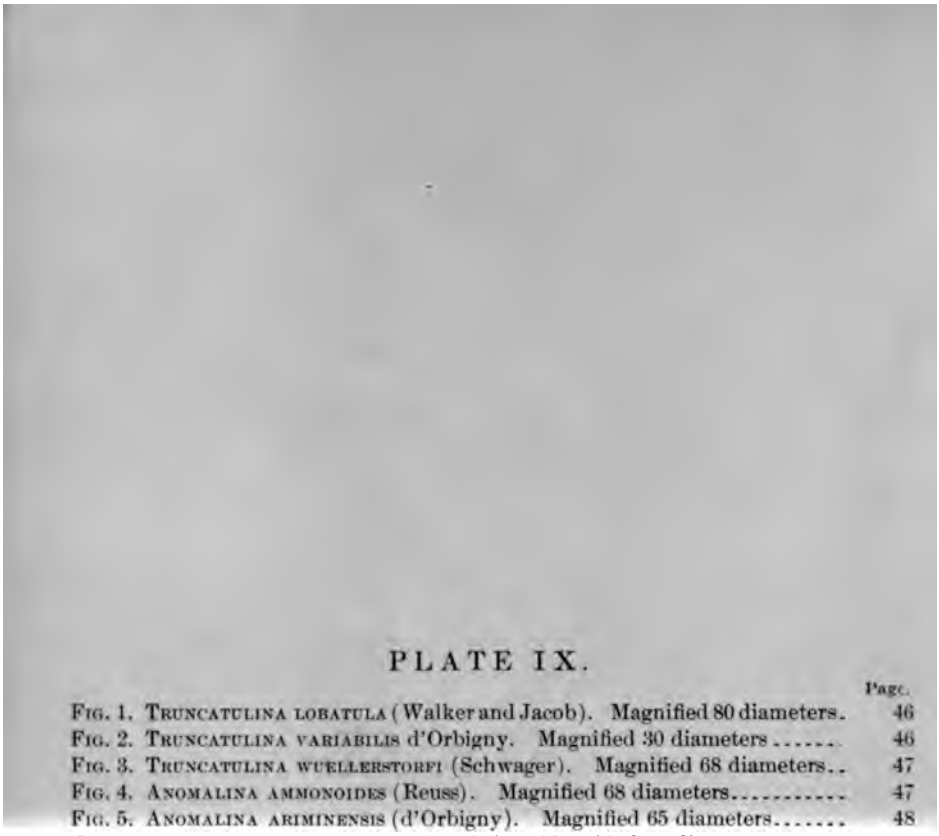

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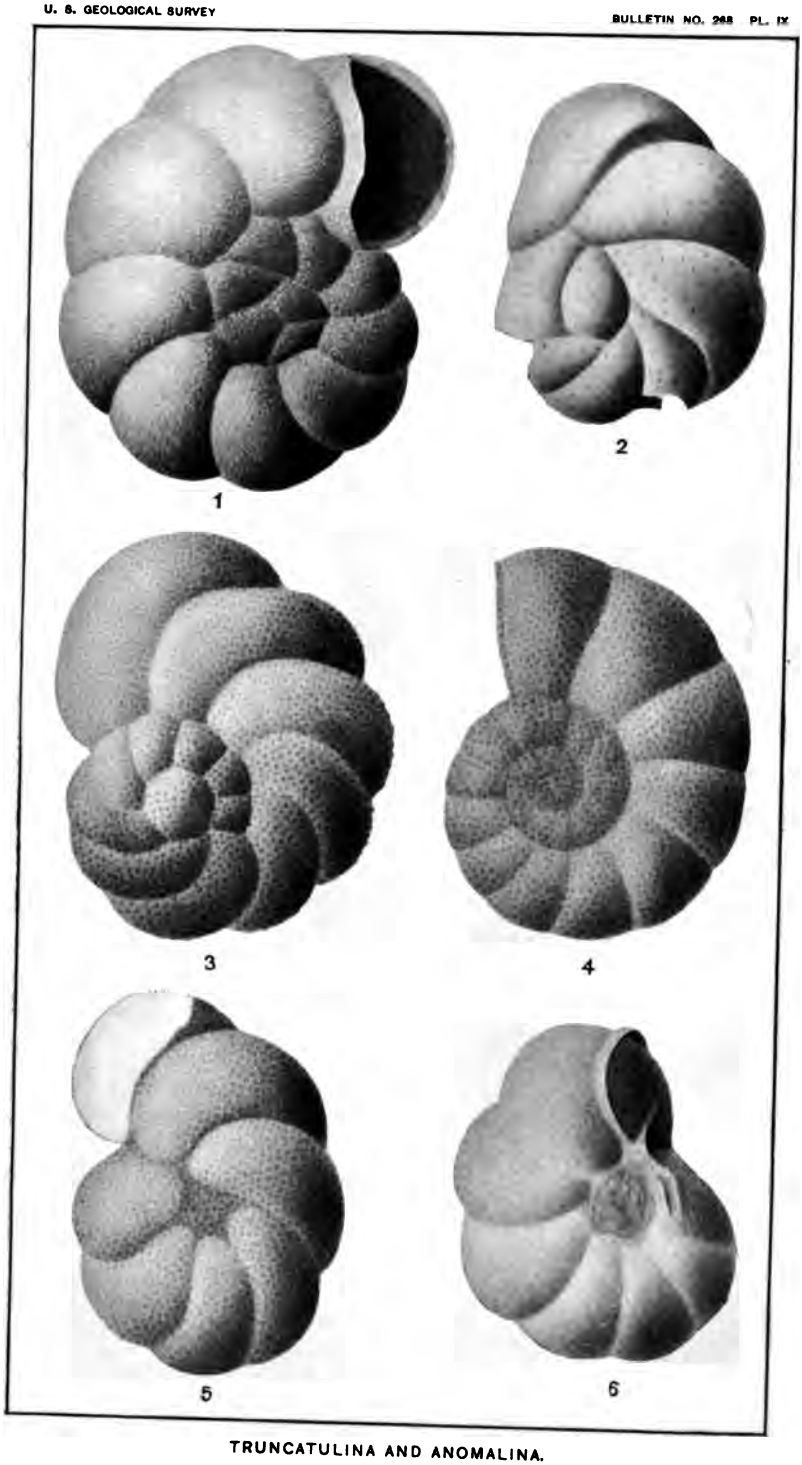
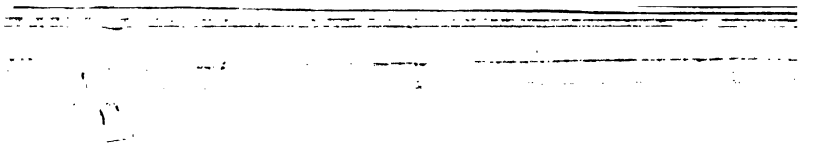


TRUNCATULINA AND ANOMALINA.



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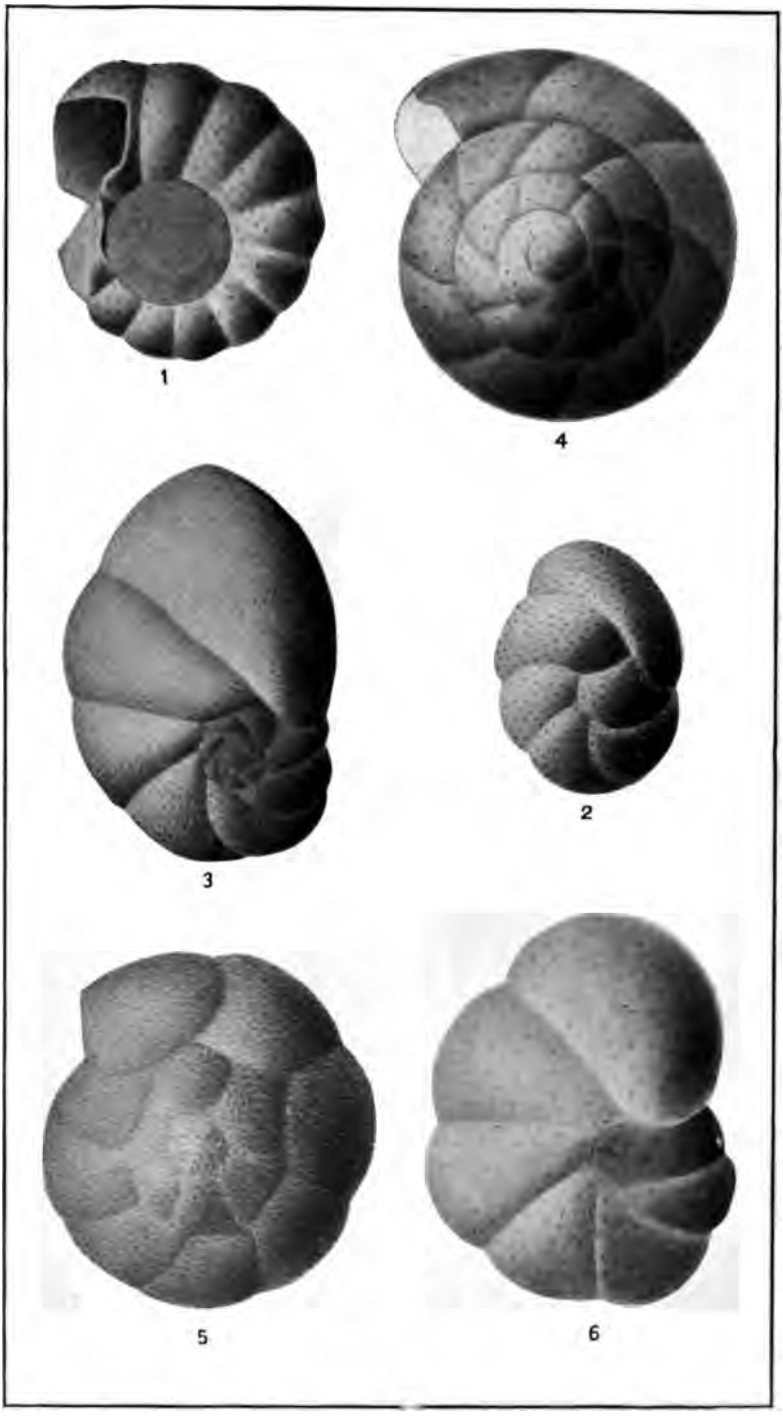

ANOMALINA, PULVINULINA, ROTALIA, AND NONIONINA.

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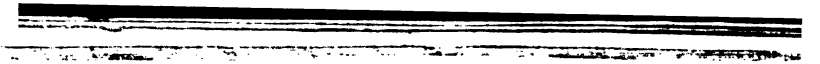

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